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# THE CANADIAN FISH CULTURIST

ISSUE THIRTY-TWO
MAY • 1964

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THE DEPARTMENT OF FISHERIES OF CANADA

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ROGER DUHAMEL, F.R.S.C.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1964

90213—1

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Editor's Note: The first three articles in this issue were among the papers presented at the annual meeting of the Canadian Committee on Freshwater Fisheries Research, held in Ottawa on January 7, 1963.


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Published under Authority

of

HON. H. J. ROBICHAUD, M.P.

Minister of Fisheries

# The Contribution of Zooplankton to the Turnover of Phosphorus in the Epilimnion of Lakes

by

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## Introduction

Will knowledge of the cycle of phosphorus in lakes help us to increase their productivity? Twenty years ago the answer to this question would have been an unhesitating "yes". Brandt (2) had previously asserted that the supply of phosphorus was the factor limiting the growth of phytoplankton and his conclusion had recently received support from the field and laboratory studies of Atkins (1) and Harvey (6), and Einsele's (3) fertilization experiments in freshwater. Einsele had added massive amounts of inorganic phosphorus to the surface of Schleinsee and found that the bulk of this phosphorus was removed from the water by phytoplankton within a week and that in a month the concentration of inorganic phosphorus had returned to its original low level. Thus, the relation between phosphorus and productivity appeared to be direct, simple and well established.

Then phosphorus began to slip from its apparently unassailable position and a few of the observations contributing to its fall deserve mention. First, on many occasions the concentration of inorganic phosphorus was not observed to decrease as the population of phytoplankton increased, in fact, the opposite relation was occasionally observed. This suggested that the water was not the main storage depot for inorganic P, but was merely a temporary reservoir which could be replenished from unknown sources of supply more rapidly than it could be emptied by growing phytoplankton. Thus the picture began to change from a simple, static one into one in which phosphorus was rapidly cycled throughout the aquatic ecosystem, and it became obvious that little more could be learned about the role of phosphorus unless new methods of studying it became available.

The new tool, radioactive isotope technique, which made possible further advances also served to cast doubt on the earlier conclusions about the role of phosphorus as a limiting factor. Rodhe (13), using the $C^{14}$ method of Steeman Nielsen (15), showed that in one lake the primary productivity of surface water was increased far more by the addition of a little hypolimnetic water than by the addition of phosphorus. Finally, Goldman (4), also using $C^{14}$ technique, has shown that trace amounts of any one of a variety of elements such as Mo, Co, Zn or Mn, increase the productivity of the surface waters of certain lakes. The result of these studies is that the relation between phosphorus and productivity is not as direct or obvious as it once appeared to be. However, I do not mean to imply that there is no relation, for when we talk of "the energetics



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of productivity" we are talking about the flow of energy through an ecosystem and in any system involving living things the flow of energy and the cycle of an element, regardless whether the element is Mo, Co, N or P, are inseparable. Before we can increase and direct the productivity of lakes as we do that of the land we will have to know much about the cycle of phosphorus as well as the cycles of many other trace elements.

I would now like to outline briefly what radioactive tracers have helped us to learn about the cycle of phosphorus and the role of zooplankton in this cycle. My hope is that you will be impressed not so much by what we know, as by our increasing awareness of what we do not know. I will first consider the cycle of phosphorus in the whole lake, then within the epilimnion, and finally the contribution of zooplankton to the cycle within the epilimnion.

## Phosphorus Cycle in the Entire Lake

Whenever the cycle of an element is studied within a cell, organism or ecosystem, the object of the study is thought of as consisting of compartments, a compartment being an operationally recognizable region in space or a chemical compound or group of compounds (14). For example, if the cycling of phosphorus within a mammal were under study, two major compartments, extracellular and intracellular, could be recognized. Each of these could be subdivided, the extracellular into the rapidly exchanging phosphorus in blood and lymph and the relatively firmly bound phosphorus in bone, and the intracellular into mobile phosphorus of metabolic intermediates and fixed phosphorus in structural materials and DNA. Small lakes are conveniently divisible into three compartments, (*a*) open water and organisms of the epilimnion, (*b*) littoral organisms, and (*c*) the hypolimnion and mud. The lake is not a closed system, but has contact *via* the epilimnion with the phosphorus of the lake's drainage basin, since phosphorus enters with the inflowing water and leaves with the outflowing water. It is important to realize that the division I have used is not the only possible one. For example, a limnologist who is primarily interested in the role of the mud might prefer to treat the epilimnion and littoral region as one compartment and separate the water of the hypolimnion and the mud into two compartments. However, when one is primarily interested in the trophogenic zone, the division I have given is a useful one, particularly so since the epilimnion and the trophogenic zone extend virtually to the same depth in many small lakes.

The first conclusion to come from the application of compartmental analysis to the results of tracer experiments was that the phosphorus in the epilimnion is much more mobile than it had been previously thought. The turnover time of phosphorus (the time in which an amount of phosphorus equivalent to the total amount in a compartment leaves that compartment and a similar amount enters it) in the epilimnion of one lake was found to be 3.6 days (10). A summary of the movements of phosphorus through this lake is given in Figure 1. which shows that the littoral region is the most important contributor to the turnover of phosphorus of the epilimnion, phosphorus being lost to this compartment ten times as fast as to the hypolimnion and mud and fifty times more rapidly than

through the outlet. During the experiment return of phosphorus from the littoral region was about 20% higher than loss to the littoral and more than compensated for the various losses. The mechanism causing this rapid exchange is still unknown, but it is obvious that a slight change in the balance between rate of loss to the littoral and gain from the littoral could cause the rapid changes in the total P often observed in the epilimnion. However, it must be remembered that this information is available for only one lake, a small acid-bog lake with a well developed littoral zone. Probably in different types of lakes, such as oligotrophic lakes with a poorly developed littoral zone, or lakes with large drainage basins and consequently a large flow through, entirely different factors might determine the phosphorus content of the epilimnion.

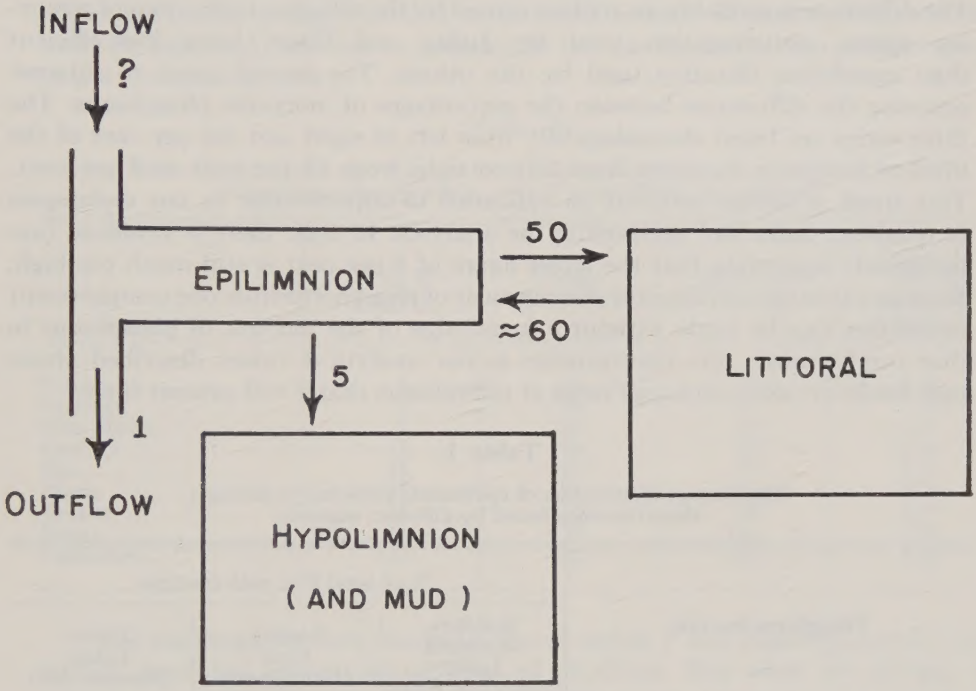


FIGURE 1. Diagram to illustrate the three major compartments of phosphorus in a lake. The numbers indicate the relative fluxes of phosphorus between compartments in Toussaint lake in midsummer.

## Phosphorus Cycle Within the Epilimnion

Until now I have spoken as if phosphorus occurred in only one form because I have only been considering the exchange between the major compartments. But to discuss the cycle within a compartment the various forms of phosphorus must be considered. These are, (*a*) inorganic P dissolved in the water, (*b*) organic P compounds dissolved in the water, (*c*) seston P, or phosphorus in particulate matter. The last can be further subdivided into phosphorus in phytoplankton, zooplankton and in non-living particles.

Before considering the cycle of phosphorus through these subcompartments I will digress for a moment to show the embryonic state of our knowledge of the distribution of phosphorus amongst these fractions. Table I. shows a summary of the results of three workers in different parts of North America, each of whom measured the distribution of total P amongst the above fractions. The first observation to note is that Juday and Birge found 2.3 times as much phosphorus in the soluble organic form as in the seston, but the other two workers found almost the inverse ratio (0.44). Hutchinson (7) noticed the difference between his and Juday and Birge's (8) results and attributed it to geographical differences, the Wisconsin lakes being more highly coloured than Linsley pond. However, this explanation now appears invalid because in the series of Ontario lakes the ratio was the same in the most highly coloured as in the most colourless lakes. The difference is probably an artifact caused by the different techniques of removing seston, centrifugation used by Juday and Birge, being less efficient than membrane filtration used by the others. The second point of interest concerns the differences between the percentages of inorganic phosphorus. The three series are listed chronologically from left to right and the per cent of the total as inorganic decreases from left to right from 13 per cent to 5 per cent. This trend is almost certainly an indication of improvement in our techniques of handling water and performing the analyses. In fact, there is evidence (unpublished) suggesting that the latest figure of 5 per cent is still much too high. Since no calculation of the rate of movement of phosphorus from one compartment to another can be made without a knowledge of the amount of phosphorus in that compartment, the uncertainties in our analytical values described above cast doubt on some exchange rates of phosphorus that I will present later.

Table I.

The average distribution of epilimnetic phosphorus amongst three fractions found by different workers.

| Phosphorus fraction | % of total P in each fraction | | |
|---|---|---|---|
| | Northern Wisconsin Lakes (Juday and Birge) | Linsley Pond (Hutchinson) | Ontario Lakes (Summer Av.) |
| Inorganic | 13 | 9.5 | 5 |
| Soluble Organic | 61 | 28.5 | 29 |
| Seston | 26 | 62 | 66 |

One of the first and most startling observations made when studies of the cycle of phosphorus within the epilimnion were begun was the extremely short turnover time of inorganic P due to an exchange of phosphorus between the water and the seston. This exchange is caused by living organisms, primarily the aquatic bacteria, which are continually taking up and releasing phosphorus. Table II. shows the turnover time of inorganic P in the surface water of nine lakes. The first three columns are simply to define the lakes and show that they

were of widely different types, varying in productivity (as indicated by total P concentration), water colour and hardness. The fourth column shows that regardless of these differences, the turnover in all the lakes was similar, ranging from two to seven minutes. Apparently a rapid turnover of inorganic phosphorus of the epilimnion is a general phenomenon, and one suggesting that inorganic P, if not limiting for the growth of phytoplankton, is indeed in short supply.

Another pool of phosphorus which might be expected to be available for phytoplankton is the soluble organic P. Many laboratory studies have indicated that a variety of aquatic plants and animals can utilize and produce some organic phosphorus compounds, but as yet none has demonstrated a turnover of the soluble organic P, in lakewater. Perhaps some of it, unavailable to phytoplankton and particularly resistant to bacterial decomposition enters with the inflowing water and passes through the lake to the outlet unused. These are problems that must be answered if we are to understand the significance of this compartment in the phosphorus cycle.

Table II.

Some characteristics of a series of Ontario lakes and the average turnover time of inorganic phosphorus in surface water during the summer.

| | Total P ( $\mu$g/1) | Colour (Pt. scale) | Hardness (EDTA) (mg/1) | Turnover Time of Inorganic P (min) |
|---|---|---|---|---|
| Found | 5 | 6 | 28 | 6.6 |
| Opeongo | 7 | 20 | 23 | 7.4 |
| Two Rivers | 7 | 24 | 17 | 7.5 |
| Costello | 12 | 30 | 25 | 5.4 |
| Eos | 18 | 162 | 27 | 2.2 |
| Mary | 27 | 11 | 176 | 3.3 |
| Teapot | 33 | 42 | 92 | 1.9 |
| Heart | 44 | 23 | 136 | 7.3 |
| Grenadier | 133 | 12 | 232 | 3.0 |

The exchange between inorganic P and seston P was demonstrated by field studies involving natural populations of plankton. But when we attempt to split the seston compartment in order to differentiate between the activities of phytoplankton and zooplankton we encounter practical difficulties since for physical separation of the plankton we still depend on differential filtration which is unsatisfactory because the largest phytoplankters are larger than the smallest zooplankters. Consequently our knowledge of the role of zooplankton has come from laboratory studies of single species. The following results are derived largely from a study of *Daphnia magna*, a large Cladoceran. The rates of uptake and release of zooplankton will be calculated using 1 mg. as an average for the dry weight of zooplankton per liter in epilimnetic water and on the dangerous assumption that the effect of this 1 mg. would be the same whether it were composed of 4000 rotifers or four *Daphnia magna*.

The first question investigated was whether or not zooplankton, like bacteria, influence the phosphorus cycle by taking up and releasing inorganic P. It was

found that they do take up inorganic P directly from solution, but this uptake is insignificant, both in its effect on the phosphorus cycle and as a means of supplying zooplankton with phosphorus. To compare the amounts of phosphorus moving between the various compartments arbitrary figures which have meaning relative to each other can be used. If the direct uptake by zooplankton is made to equal one, then the exchange of inorganic P between the water and phytoplankton would equal 1200. Obviously direct uptake by zooplankton is negligible compared with direct uptake by bacteria. It is small even when compared with the minimum phosphorus requirements of zooplankton for they lose inorganic P in their urine and this loss equals three on our arbitrary scale (11).

The main source of phosphorus for zooplankton is the seston which they filter from the water. Collectively they filter about 1 per cent of the water volume every hour (12) and this represents a phosphorus intake of 15 units of which about 12 units is assimilated and 3 returned to the water in feces (9). The fecal phosphorus is probably partly regenerated as inorganic P and partly lost to the hypolimnion as the pellets sink to the bottom. If the phosphorus budget of zooplankton is calculated now, the result is a net gain of 10 units. This is certainly more apparent than real for the zooplankton population neither increases indefinitely nor continues to accumulate phosphorus. The discrepancy is caused by a neglect of several factors, predation probably being the most important because about 25 per cent of the zooplankton population can be

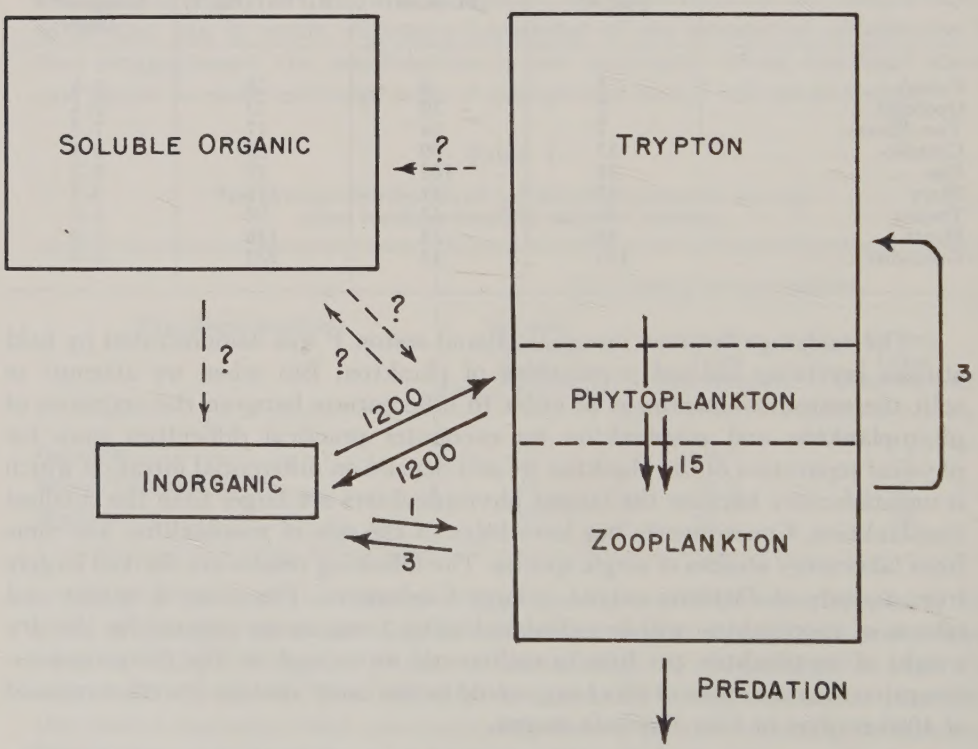


FIGURE 2. A summary of our knowledge of the movements of phosphorus between subcompartments within the epilimnion. The area of the rectangles is proportional to the phosphorus content.

removed daily by predation during the summer (5). Another factor is that the direct loss of phosphorus was measured on starving animals and is probably much higher in animals feeding normally. Finally the estimate of uptake of phosphorus due to feeding is probably too high because it was based on the assumption that all species of phytoplankton are consumed by zooplankton; whereas it is likely that many of the larger algae such as *Anabaena* are not eaten. The cycle of phosphorus within the epilimnion, as it has been described here, is summarized in Figure 2.

At this point the question of the significance of this information must surely arise. Is the information summarized in Figure 2 of any practical value, particularly to one interested in the production of fish? I think that the answer is obviously 'no'. Our knowledge, which is still far too incomplete is derived from experimental and analytical techniques that are still imperfect and is based on assumptions that are still untested. Viewed in this light, the main value of Figure 2 is that it makes us aware of our lack of knowledge and serves to suggest the direction of further research.

## Acknowledgments

The previously unpublished studies of phosphorus concentrations and turnover in Ontario lakes was supported by research grants from the National Research Council of Canada, and the University of Toronto Advisory Committee on Scientific Research.

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# Flatworm Problems in Fish

by

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Flatworms, which include the tapeworms and flukes, frequently are the most obvious parasites of freshwater fish. Wormy fish make a tremendous impression on our esthetic sensibility. What is equally or more important, from the standpoint of a fishery, is whether these worms interfere with the health and growth of the fish. Here is a brief summary about 1) the effects of flatworms on fish, and 2) how fish react to these unwanted guests.

Trematodes, or flukes, are divided into two broad groups: the Monogenea and the Digenea. Monogenetic flukes, which occur mainly on the skin and gills of fish, do not require an intermediate host and actively transfer from fish to fish. Usually, therefore, all stages of development of these flukes occur on the same fish. Most adult digenetic flukes live in the gut but the larval stages occur in the musculature, liver, lens of the eye, etc. There are two or more hosts in their life cycle, the first intermediate host being a mollusk. Larval digenetic flukes transfer to the fish either directly by their own activity, or passively along with the food eaten by the fish; the adult flukes normally do not move from fish to fish. It is most unusual to find both larvæ and adults of the same species of digenetic flukes in the same species of fish.

Cestodes, or tapeworms, also are divided into two groups: the Cestodaria and the Cestoda. The former are rare and of no importance in North America. All other cestodes of fish for which the life cycles are known require some invertebrate, frequently a copepod, as the first intermediate host. Larval cestodes transfer passively to the fish along with infected food. Adult cestodes occur only in the gut, but larval stages when present occur in various parenteral sites or in the gut. Some species of cestodes may occur both as larvæ and adults in the same species of fish.

Can and do flatworms kill fish? Apparently the adult stages in the gut rarely cause serious harm. In nearly 700 fish which we have examined in Algonquin Park, even the heaviest infections in the digestive tract revealed no more than an occasional slight area of inflammation or nodule formation. Such surveys may be misleading however. For example, Margolis (1963) found that *Eubothrium salvelini* killed very young salmonids. This cestode is the most widely distributed cestode of trout in Algonquin Park, and although it caused little apparent harm in the fish 3 or more years of age which were examined, it may very well have serious effects on younger fish which were not sampled.



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There are two other reports of extensive fish mortality attributed to adult flatworms in the gut. Wales (1958) maintained that intestinal flukes (*Crepidostomum* sp.) killed trout in California over a 2-year period. The Norwegian worker Vik (1954, 1958) reported mortality in nature due to the cestode *Cyathocephalus truncatus*, and he showed experimentally that only a few worms caused severe inflammation and rupture of the gut wall, leading to death. Both of these worms occur in the fish of Algonquin Park, but if they cause serious harm it has gone unrecognized.

Adult blood flukes of the genus *Sanguinicola* live in harmony with their fish hosts in the circulatory system. However, the eggs they produce filter out of the blood into the gill filaments, hatch, and the emerging larvæ extensively damage the gills of fingerlings and may cause heavy mortality (Davis, Hoffman and Surber, 1961).

Monogenetic flukes have caused serious mortality among fish (e.g., *Dactylogyrus vastator* and *D. solidus* on gills of carp (Dogiel *et al.*, 1958); *Gyrodactylus elegans* on trout (Meyer, 1954)). Since no intermediate host is required, the parasites reproduce rapidly under ideal conditions, and epizootics occur when fish are crowded. Turnbull (1955, 1956) worked with *Gyrodactylus bullatarudis* on guppies in the laboratory and produced 20 per cent daily mortality with this worm by maintaining the proper degree of crowding. The number of *G. bullatarudis* present at death was related to the size of the fish; 105 killed a fish $\frac{3}{8}$ inch long, but a fish four times as long had 40 times as many flukes at death. The larger fish showed little discomfort with up to 100 parasites.

Larval digenetic flukes migrating to various parenteral locations may cause serious lesions and mortality (Table I). As far as is known, damage is largely mechanical, frequently resulting in extensive hemorrhage. Furthermore, with rare exceptions, they must invade in large numbers at one time before mortality occurs. For example, Hunter (1942) and Hoffman (1958*a*) experimentally killed fish with massive infections of *Posthodiplostomum minimum*, yet several fish kept by Sillman (1957) showed no distress although little functional tissue remained in their livers. Conditions necessary for massive exposures to trematodes at one time may be artificially created, but are less common in nature.

Digenetic trematodes may have deleterious effects without causing mortality, although such effects are difficult to evaluate. For example, Hunter and Hunter (1938) found that a few small-mouth black bass experimentally infected with larvae of *Crassiphiala bulboglossa* lost weight compared to uninfected controls. However, most workers who have attempted to assess the effect of parasitism on naturally infected fish found no correlation between the coefficient of condition (K factor) of the fish and the concentration of larval flukes (Woodbury, 1940; Elliott and Russert, 1949; Rabideau and Self, 1953; and Fox, 1962). In fact Rabideau and Self (1953) concluded that the condition of the fish usually is affected more by related factors such as crowding and food supply than by parasitism, and that a given fish might support a high parasite burden under optimal conditions, whereas a low parasite burden may have a pronounced

## TABLE I

### FISH MORTALITY DUE TO LARVAL DIGENETIC TREMATODES

| Fluke | Definitive Host | Fish Host | Number Worms | Organs Attacked | Authority |
|---|---|---|---|---|---|
| Crassiphiala bulboglossa | Kingfisher | Fathead minnow | 400-600 metacercaria | Skin and musculature | Hoffman, 1956 |
| Diplostomum baeri eucaliae | Duck | Brook stickleback | 200-1000+ cercaria | Throughout body | Hoffman and Hundley, 1957 |
| Uvulifer ambloplitis | Kingfisher | Sunfish | Many | Skin and musculature | Krull, 1934 |
| Diplostomum flexicaudum | Gulls | Suckers, trout | Several hundred | Eye lens | Ferguson and Hayford, 1941 |
| Posthodiplostomum minimum | Herons | Wide variety | Many | Liver, other viscera | Hunter, 1942; Hoffman, 1958a |

effect if food is insufficient. Furthermore, as Fischthal (1953) cautions, finding heavily parasitized fish in poor condition does not necessarily indicate that the condition resulted from parasitism.

Unlike most larval trematodes, the larvae of cestodes are relatively large. Comparatively few of them invading the tissues can cause considerable mechanical disturbance, depending on the size of the worm, size of the fish, and the organ invaded (Table II). In heavy infections all the worms included in Table II can kill the host. However, to my knowledge, only *Diphyllobothrium* spp., or a related form, in Britain (Fraser, 1960), Ireland (Hickey and Harris, 1947), and Quebec (Hoffman and Dunbar, 1961), have caused serious mortality of trout outside hatcheries. Nearly all the lake trout in Lake Louisa, Algonquin Park, carry plerocercoids of *Diphyllobothrium* sp., but no die-offs of these fish have been observed. Even if cestodes do not cause mortality directly they may cause pronounced loss of condition in the host (Pitt and Grundmann, 1957; Dence, 1958). As more of these host-parasite relationships are investigated, undoubtedly various more subtle effects will be demonstrated. For example, Kerr (1948) found that the secretory activity of the pituitary is disturbed when fish are infected with plerocercoids of *Ligula*.

Presumably fish, like other animals, have defence mechanisms against flatworms once they have entered the body. Usually the first line, so to speak, is a more-or-less non-specific cellular response, especially by leucocytes and reticulo-endothelial cells, usually followed by more specific immunological responses. Dogiel *et al.* (1958) summarized Russian observations on changes in the blood of fish parasitized with various helminths. Consistently there is a drop in the numbers of lymphocytes with a concomitant rise in monocytes, polymorphonuclear agranulocytes, and neutrophils. Apparently these changes are related to inflammatory reactions at the sites of infection. If the host is successful then most parenteral parasites are walled off in connective tissue cysts, although for some reason this does not occur with plerocercoids of *Diphyllobothrium latum*. Usually encysted parasites live for long periods of time (Fox, 1962), although ultimately some or all die and degenerate (Miller, 1945). In addition to changes in the leucocyte picture there frequently is a drop in the hemoglobin level of the blood (Dogiel *et al.*, 1958). This supports the observation of Elliott and Russert (1949) who believe that yellow perch infected with *Clinostomum marginatum* are more susceptible to winter kill than uninfected fish, due to increased oxygen demand by the fish, and /or the inability of such fish to cope with reduced oxygen tensions in the water.

Higher vertebrates frequently develop 1) premunition, that is a resistance to reinvasion by additional parasites of the same species as long as the original infection persists, and/or 2) immunity, which is resistance to reinfection after loss of original infection with the same species.

Some fish develop immunity to monogenetic flukes as Nigrelli (1935a, 1935b) and Nigrelli and Breder (1934) observed with *Benedenia melleni* on the eye of marine fish in aquaria. They found that in an initial infection these parasites multiplied rapidly and caused mortality, but with time those fish which

## TABLE II

### FISH MORTALITY DUE TO CESTODE PLEROCERCOIDS

| Cestode | Definitive Host | Fish Host | Number Worms | Organs Attacked | Authority |
|---|---|---|---|---|---|
| Proteocephalus ambloplitis | Bass, Bowfin | Bass, other fish | Numerous | Liver, gonads, other viscera | Hubbs, 1927; Bangham, 1941; Morrison, 1957; others |
| Ligula intestinalis | Gulls | Perch, other fish | Less than 10 | Gonads, other viscera | Bangham and Hunter, 1939; Pitt and Grundmann, 1957; Dence, 1958; others |
| Diphyllobothrium spp. | Piscivorous Birds and Mammals | Trout, other fish | Less than 50 | Body cavity, viscera, musculature | Essex and Hunter, 1926; Hickey and Harris, 1947; Hoffman and Dunbar, 1961; others |
| Triaenophorus spp. | Pike | Trout, Burbot, other fish | Less than 40 | Liver, musculature | Miller and Kennedy, 1948; Dogiel, et al., 1958; Lopukhina, 1961 |

survived lost their infections, and thereafter, if reinfected at all, the worm burden was small and the parasites occupied areas of the skin not previously parasitized. Nigrelli (1935a) also showed that mucus from immune fish had a stronger lethal effect on the parasite than mucus from non-immune fish. This is particularly interesting in view of the demonstration by O'Rourke (1961) that several of the same antigens occur in both the blood and the mucus of sea bass. If blood antigens can occur in mucus, possibly antibody can be demonstrated also. It is of considerable interest to determine if other fish develop resistance against monogenetic flukes.

Hoffman (1956) showed experimentally that infections with metacercaria of three species of digenetic flukes (*Posthodiplostomum minimum*, *Diplostomulum baeri eucaliae*, *Crassiphiala bulboglossa*) conferred no resistance to subsequent challenge by the same parasite. On the other hand Krull (1934) reported that older sunfish previously infected with a few *Uvulifer ambloplitis* were refractory to further infection.

It is indeed remarkable what immense numbers of parasites may occur in apparently healthy fish, not only within the gut, but in the viscera as well. The species composition and the total numbers of gut parasites may change with the seasons as the fish ages, keeping in rhythm with changes in the feeding habits of the host (Dogiel *et al.*, 1958). Frequently there is a complete annual turnover of the parasite population in the gut (Connor, 1953; Miller, 1943), although this usually is not so with parenteral parasites where older fish carry more than younger fish (Fox, 1962). An interesting phenomenon reported by Hoffman (1958b) is the so-called "self cure" in certain fish infected with larval flukes. The abdominal wall of fish with heavy intraperitoneal infections ruptures, allowing some of the parasites to escape. This is followed by closure and normal healing of the wound. Perhaps this demonstrates better than anything what extremely heavy infections some fish can withstand and still remain alive and active.

## Summary

The foregoing brief review indicates that little experimental work has been done to study the effect of flatworm parasites on the health of fish. There are records of extensive fish mortality in natural waters due to flatworms, but apparently such catastrophes are uncommon. Generally young fish are more seriously affected than old fish, and this usually results when they are crowded. While it is uncertain if digenetic flukes cause loss of condition in fish, some cestodes definitely have an adverse effect. It appears that much of the harm caused by flatworms is mechanical, a function of size, the larger cestodes being more serious than smaller flukes, although there may be adverse biochemical effects as well. The host usually isolates parenterally located flatworms into cysts of connective tissue, a response adequate to cope with the usual light infections. There is convincing evidence that immunity develops against a particular monogenetic fluke, but neither effective premunition nor immunity has been demonstrated against digenetic trematodes or cestodes.

## Acknowledgments

I should like to acknowledge my indebtedness to the Ontario Department of Lands and Forests, particularly Mr. N. V. Martin and his staff at the Harkness Laboratory of Fisheries Research, at Lake Opeongo, Algonquin Park, Ontario, for enthusiastic co-operation and support over the past few years.

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# Selected Topics on Bacterial Fish Diseases

*by*

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The most important bacterial fish diseases are furunculosis, ulcer disease, infections caused by *Aeromonas liquefaciens* and *Pseudomonas fluorescens*, kidney disease, and mycobacterioses. In addition to the above listed diseases fishes very often suffer from diseases caused by representatives of a separate order of bacteria called *Myxobacteriales*. Fish diseases caused by myxobacteria are called myxobacterioses. The most important myxobacterioses are columnaris disease, gill disease and the coldwater-peduncle disease syndrome.

It is almost axiomatic with the medical profession to accept that an exposure to pathogenic bacteria results in an infectious disease. This way of thinking was the result of the almost explosive growth of medical bacteriology during the recent past. Virology is almost in the same stage of development now.

Epidemiologists have questioned this attitude for some years, and present day thinking was very dramatically expressed recently by Dr. René Dubos (1955) from the Rockfeller Institute in New York:

"The germ theory of disease has a quality of obviousness and lucidity which makes it equally satisfying to a schoolboy and to a trained physician. A virulent microbe reaches a susceptible host, multiplies in its tissues and thereby causes symptoms, lesions and at times death. What concept could be more reasonable and easier to grasp? In reality, however, this view of the relation between patient and microbe is so oversimplified that it rarely fits the facts of disease. Indeed, it corresponds almost to a cult generated by a few miracles, undisturbed by inconsistencies and not too exacting about evidence.

"There are many situations in which the microbe is a constant and ubiquitous component of the environment but causes disease only when some weakening of the patient by another factor allows infection to proceed unrestrained, at least for a while.* Theories of disease must account for the surprising fact that, in any community, a large percentage of healthy and normal individuals continually harbor potentially pathogenic microbes without suffering any symptoms or lesions. This type of dormant infection seems to occur widely, not only among men and animals, but also probably among plants and even microscopic cells.

"Thus the simple fact that a population survives and flourishes in a given environment implies that its members are endowed with a high degree of natural

* In fishes: Columnaris disease, infections caused by pseudomonads and gill disease, are examples of this relationship.



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resistance to the microbes normally present in that environment. This natural resistance stems in part from evolutionary selection of the strains best endowed with mechanisms for withstanding infections, and probably in part from the development of adaptive reactions in response to early exposure to the microbes. Suffice it to say that their over-all effect is the establishment of a state of biological equilibrium between man or animals on the one hand, and the microbes endemic in the community on the other."

This type of a balance between pathogens and hosts was established by the exposure of humans to some of the infectious diseases for many generations and by the survival and reproduction of most resistant individuals. In the textbooks of epidemiology there are described "new" epidemics which occurred when populations were exposed to a pathogens with which they had no previous experience. Even in a population in which a well-established balance exists between a pathogen and the host, an acute epidemic may develop if individuals, or the entire population is exposed to unfavorable conditions. It is fashionable now to call this a "stress."

The laws of epidemiology can be applied to infectious diseases of animals, fishes included, but the name of the discipline should be rightly changed to epizootiology.

When a person, or a population, develops an infectious bacterial disease, modern control methods call for the treatment of affected individuals with sulfonamides or antibiotics, and the protection of the still healthy individuals by immunization and sanitation. The same is true in case of larger farm animals and smaller pets.

In case of poultry, where the value of individual birds is small, epizootics are usually controlled by mixing drugs with food and drinking water and the isolation of the still healthy flocks.

Approach to the control of bacterial diseases of freshwater fishes is quite similar to that employed in control of poultry diseases. There are, however, very great differences between poultry and fishes. Birds are warm blooded terrestial animals, and fishes are cold-blooded aquatic animals. The first consequence of this is that homeostasis is much less advanced in fishes. The second consequence is that while the air around the land animals usually contains a fairly uniform amount of oxygen, and other gases, water in which fish live contains only a small fraction of the oxygen present in the air, and this small amount may vary greatly from place to place, and even from hour to hour. Particularly in fish hatcheries the dissolved oxygen, and ammonia, the latter resulting from fish metabolism, are usually very close to marginally safe concentrations.

The metabolic rate of fishes depends on the ambient temperature. It is important to note, therefore, that demand for dissolved oxygen is greater at higher temperatures, while at the same time the solubility of this gas in water decreases. During the summer months fishes are often exposed during daylight to supersaturation with oxygen produced by submerged vegetation, but at night they may suffocate in the same pond due to deficiency of dissolved oxygen. Both supersaturation and deficiency of oxygen may cause losses on their own account, or to lower the fish resistance to infective agents.

Another important fact is that the speed with which fishes produce antibodies in reaction to infection and immunization depends on temperature. At very low temperatures the immune response is either absent or very slow (Reddecliff, 1960).

Debilitation of fishes during the winter months often results in anemia and reduction in plasma proteins. This is coupled with a very slow immunologic response. It may explain why usually the highest losses in warmwater freshwater fishes occurs in spring when resistance of fishes to systemic bacterial infections is at the lowest level (Liebmann, Offhaus and Riedmüller, 1960).

With this background in mind I should like to discuss now some of the most important bacterial fish diseases.

First, I should like to make a few comments on fish furunculosis. Bruce McCraw (1952) a Canadian who graduated from the Guelph School of Veterinary Medicine, wrote an excellent review paper on this disease. Therefore my remarks will be limited to the discussion of the progress made in the control of furunculosis.

Snieszko, Griffin and Friddle (1952) have shown that furunculosis can be controlled by oral administration of sulfonamides and antibiotics as terramycin and chloramphenicol. Work on nitrofurans was recently further expanded by Post and Keiss (1962).

Control of furunculosis by means of therapy depends on the resistance of the host to the disease, the virulence of the pathogen, drug resistance of the pathogen, the pharmacological effect of drugs on the specific host treated, and the influence of environment.

From the results reported by Wolf (1954) and Snieszko, Dunbar and Bullock (1959) in regard to susceptibility of trout to furunculosis we know that there are hatchery strains of brook trout which differ very much in this respect. On the other hand we know very little about the degree of virulence among different strains of *Aeromonas salmonicida*. We have only found that strains of this bacterium which are resistant to sulfonamides are less virulent. We know also that *A. salmonicida* becomes easily resistant to sulfonamides and Terramycin. We encountered strains resistant to nitrofurans, but so far we did not find strains resistant to chloramphenicol. This drug is one of the best for control of furunculosis, but due to its high cost, is used infrequently and this may explain why chloramphenicol resistant strains of *Aeromonas salmonicida* so far had not been reported.

The knowledge of the pharmacological properties of drugs is very important. While sulfamerazine is well tolerated by brook and rainbow trout, it completely arrests growth of brown trout (Snieszko and Wood, 1955). Prolonged treatment with sulfonamides can result in an irreparable kidney damage to trout as reported by Wood, Yasutake and Snieszko (1955). There are also unpublished reports on the toxicity of nitrofurans to salmonids. Nitrofurans decompose rapidly if mixed with diets containing fresh liver, therefore, diets medicated with Furoxone have to be prepared immediately before use in order to safeguard the effectiveness of this drug.

Furunculosis is also affected by temperature. The late Louis Wolf told me that this disease stops at temperatures below 8° C (45°F) but according to our observations it will cause mortalities, even in furunculosis resistant brook trout, at temperatures of 18 to 20°C (62–65°F). The effective control of furunculosis under wild conditions seems to be practicable only by stocking with strains of trout resistant to this disease.

This is all I intended to say about furunculosis. Next on my list are diseases caused by myxobacteria.

Myxobacteria are very different from other groups of bacteria. They are motile but do not possess flagella which are bacterial organs of locomotion. Instead the cells are flexible and secrete mucus. They are slowly motile by means of a combination of locomotion employed by snakes and snails.

I know of only one, very recent, report on a human disease caused by a myxobacterium. No myxobacterial diseases are as yet reported in other groups of vertebrates, except freshwater fishes, and in one occasion in tadpoles. Myxobacteria are probably responsible for the largest number of cases of bacterial diseases of freshwater fishes.

The most common myxobacterial fish diseases are gill disease, columnaris disease and the peduncle-coldwater disease syndrome.

Bacteriological methods for differentiation of fish pathogenic myxobacteria are still very unsatisfactory, so that correct diagnosis of myxobacterial diseases is still based largely on symptomatology.

Typical columnaris disease is characterized by necrotic lesions of the intergument and gills. In peduncle and cold water disease there is less necrosis, but chiefly a clean erosion of skin and musculature, resulting in pale colored ulcerations. In gill disease there is proliferation and hyperplasia of gills with fusing and clubbing of gill filaments and lamellae, but without necrosis.

Long, thin, gram negative, flexible rods can be demonstrated in the lesions of fish affected with myxobacterioses. In columnaris, peduncle and coldwater disease systemic infections are also common and myxobacteria can be demonstrated and isolated in pure culture from internal organs. A systemic myxobacterial infection is so far not reported in gill disease.

Myxobacterioses are mainly environmental diseases, and their outbreaks usually can be prevented, or their progress stopped, if not too far advanced, by restoration of optimal environmental conditions. The chief predisposing factors in myxobacterial diseases are a too high or a too low temperature, mechanical injury due to handling and crowding, which results in the lowering of dissolved oxygen to critical concentrations, and in the increase of products of fish metabolism, ammonia in particular, in concentrations higher than 0.5 p.p.m.

For treatment of superficial myxobacterioses disinfectants are recommended. The most often used are organic mercurials as piridylmercuric acetate and Lignasan $\chi$ added to water at a rate of 1 or 2 ppm for one hour. Quarternary

ammonium disinfectants as Roccal are also very effective. Some observations, but not critical experiments, indicate that copper sulfate added to water at 1 ppm may control columnaris disease in warmwater pond fishes.

In systemic myxobacterioses the drug of choice is oxytetracycline (Terramycin) given with food orally at a rate of 50 mg/kg/day. Oral administration of sulfamerazine and sulfadiazine at a rate of 200 mg/kg/day is partially effective.

Gill disease is endemic in many hatcheries of salmonid fishes receiving water from open streams. If it is not controlled by periodic use of external disinfectants it may cause very high mortalities. In all myxobacterioses one ounce of prevention and chemoprophylaxis is much better than a pound of cure.

The last disease I wish to comment on is kidney disease of salmonid fishes which is common in the United States and probably also in Canada. It is caused by a very difficult to culture corynebacterium. All hatchery propagated salmonid fishes are susceptible to this disease. The typical symptoms are white lesions in the kidney. These lesions contain gram positive, small deplobacilli. Superficially similar lesions but without bacteria are signs of visceral granuloma, which is a different and quite common disease of brook trout. Very interesting observations about the occurrence of kidney disease in the United States were made recently. This disease is common in northwest, northeast, and in the southern Appalachians. In all these areas the hatchery water supply is low in mineral contents and water can be classified as soft. In most of the hatcheries with water supply originating in limestone springs, kidney disease is very rare, and in hard water hatcheries even the experimental introduction of kidney disease is difficult.

Warren (1963) compiled data on the chemical composition of water supply in federal hatcheries for salmonid fishes, and on the incidence of the kidney disease. This compilation indicated that there was a very close correlation between the hardness of water and the incidence of kidney disease. The softer the water the greater was the incidence and severity of this disease.

I have observed that in hatcheries located in the east, at which the incidence of kidney disease was high the external fish parasites were also abundant. Wolf and Dunbar (1959) found that even small pinpricks would greatly facilitate experimental infection of trout with a pure culture of the kidney disease bacteria. This could explain why fish with lesions caused by external parasites could become more easily infected with kidney disease bacteria.

The awareness of this correlation should not be confused with the understanding of a casual relationship. In this respect we are still completely ignorant. At this time one can only say that environmental factors apparently play an important role in the incidence of kidney disease.

In concluding this paper I should like to say that the best promise for a long-range and effective control of freshwater fish diseases is not in drugs and disinfectants, but in understanding of the genetic resistance to diseases, and in furnishing the hatchery fish with the optimal environmental conditions.

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# Planting Brook Trout (*Salvelinus fontinalis* [Mitchill]) in Estuarial Waters

*by*

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## Abstract

Planting hatchery-reared brook trout of the year in the estuary of Ellerslie Brook, Prince Edward Island, resulted in a survival of 28 per cent to the anglers in the following season. These fish, age 0 and approximately 4 1/2 inches in length could have experienced salinities ranging from 0 to 30‰.

## Introduction

Brook trout (*Salvelinus fontinalis* (Mitchill)) run to salt water from most coastal streams of the Atlantic provinces of Canada, and may be angled in estuaries. At Ellerslie Brook, Prince Edward Island, a counting-fence, maintained throughout the year at the mouth of the stream, has permitted record of movements of trout between fresh and salt water over the period 1946–62 (Smith and Saunders, 1958). A pond was formed on the lower part of Ellerslie Brook in 1952. Subsequently the movements of brook trout to salt water were markedly reduced, from a yearly average (7 years) of 1,554 before pond formation to 311 (8 years) after damming. In late autumn, 1961, hatchery-reared brook trout of the year were planted directly into Ellerslie Estuary. The objective was to compensate for the loss of native Ellerslie trout to the estuary as a result of pond formation, and thereby to increase the trout stocks for angling in the Ellerslie System (stream, pond and estuary) as a whole. In general practice young hatchery-reared brook trout have been planted in fresh waters.

## Ellerslie Brook and Estuary

Ellerslie Brook is a small stream about six miles long, which, together with its estuary, is tributary to Malpeque Bay on the north shore of Prince Edward Island (Figure 1). Since the brook trout were planted in the estuary in late autumn, we have particular interest in the winter estuarial conditions.

In most years the estuary is ice-covered for about 4 months, with observed extremes of 3 1/2 to 6 months (Needler, 1941). In the winter of 1961–62 the estuary froze over on December 15, and opened, progressively from the head of tide seaward, during the period April 3–13. Tidal amplitude in the estuary is small, from 2 to 3 1/2 feet.



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Certain hydrographic features of Ellerslie Brook, its tributary, and contiguous saltwater areas, have been reported (Needler, 1931, 1941; Smith and Saunders, 1956, 1958). Stratification with respect to temperature and salinity prevails in the estuary under ice cover, as observed by Needler (1941) over a period of years (1930–38) at a station in 4 metres of water about 1 mile below head of tide. Water of low salinity (not below 2‰) persists in a stratum of 15 cm to 1 m in thickness at the surface under the ice. Salinities rise to 20–30‰ below a sharp halocline. Temperature of water in the upper stratum fluctuates closely around 0°C, while that in the more saline bottom waters falls to −1°C, or somewhat lower. With little run-off from the stream in winter, salinities of 15 to 25‰ are encountered virtually to the head of the estuary.

## Planting

*Background*

Studies have shown that native trout ran from Ellerslie Brook after reaching a length of 4 inches. They made few movements between fresh and salt water after becoming acclimated to 0°C. Trout wintered in the estuary and returned to the brook, or to the head of the estuary, in the spring (Smith and Saunders, 1958). Most of the estuarial angling is carried on at the head of the estuary.

It was assumed that the pattern of seasonal movements of hatchery-reared trout, in respect to the estuary, would be similar to that observed for native trout. Accordingly, hatchery-reared trout planted in the estuary in late autumn should winter there and move to the head of the estuary in spring.

*Stock*

The stock consisted of the progeny of brood stock held at Cobequid Fish Culture Station, Nova Scotia. The fry were transported to Cardigan Fish Culture Station, Prince Edward Island, between May 30 and June 6, 1961. From there they were carried by truck (3 hours) to Ellerslie Brook on November 29, 1961. They were 30 weeks of age when planted.

*Planting sites*

There were two planting sites, (1) a tidal pool in the area between the dam and the estuarial counting-fence, and (2) a short (50 yards) section of the estuary 300 yards below the counting-fence. The sites are shown in Figure 1. Depths in the pool at the upper site range from a few inches to 5 feet at low tide, average depth about 2 feet. Water from the pond discharged into the pool. Depths at the lower site ranged from about 5 or 6 inches at low tide to 2 feet or more at high tide. Depths at the lower site are quite representative of the upper one half mile of the estuary.

*Planting procedure*

The hatchery trout were delivered to Ellerslie Brook November 29 and were placed in cages in the pond. Half of them were then marked by removal of the adipose fin. Both ventrals of all the fish had been clipped at the hatchery. The fork lengths of a sample (352) were recorded and the combined weight of

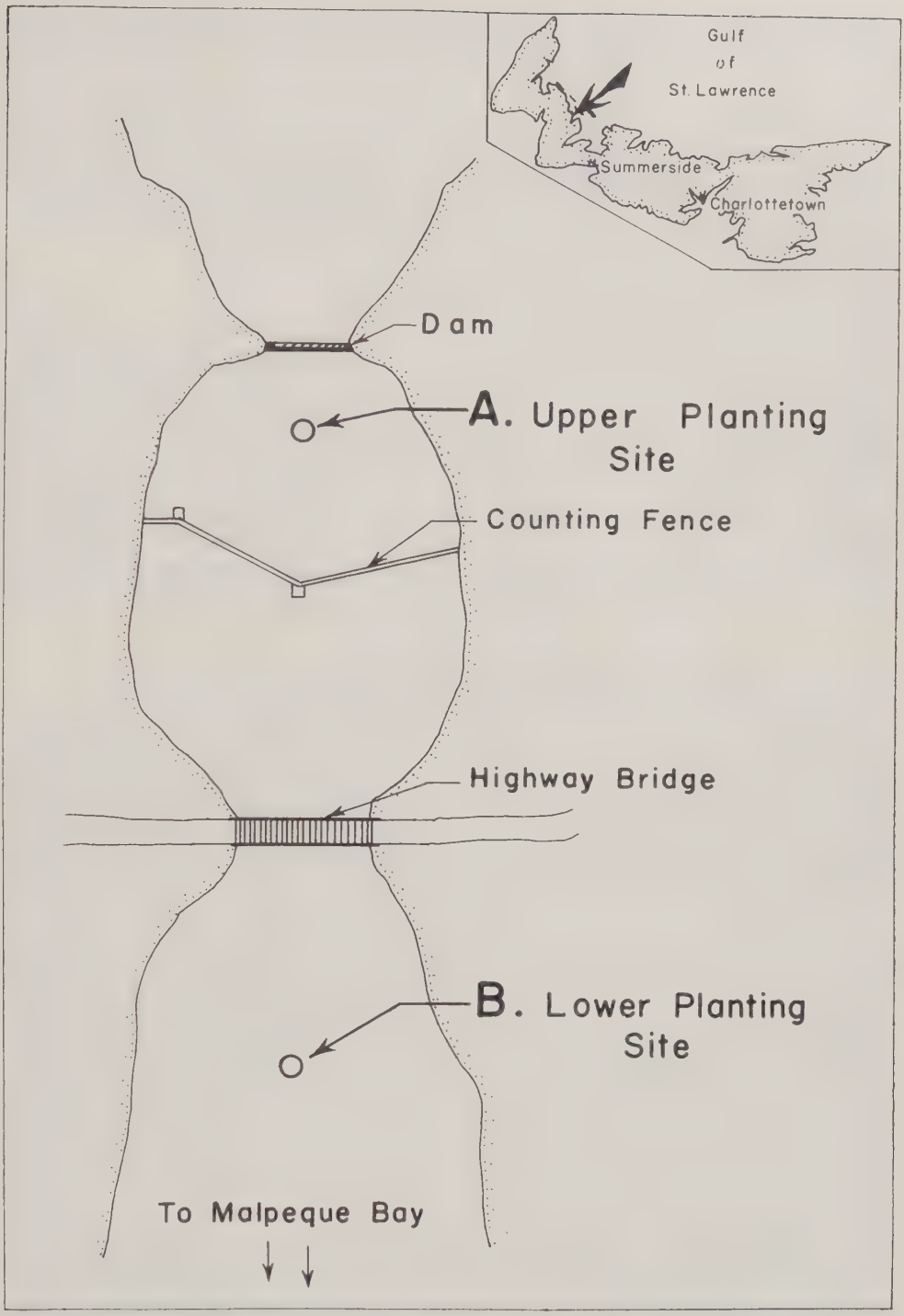


FIGURE 1. *Schematic drawing of upper part of Ellerslie Estuary showing the two planting sites. Distance from A to B approximately 300 yards. Location of Ellerslie Brook indicated by arrow on insert map of Prince Edward Island.*



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all the stock was determined. Both groups (A, RV, LV; and RV, LV) were held in the pond until December 1. There were no immediate mortalities resulting from handling, marking or holding.

On December 1, 948 (RV, LV) trout were liberated in the pool below the dam, and 980 (A, RV, LV) were released at the lower planting site. At each site 25 trout were held in cages. There were no deaths among the caged individuals up to the time of their release on December 16. Because of the formation of ice in the estuary, it was impossible to hold them for a longer period.

*Hydrographic conditions in estuary at time of planting*

The plantings were made on the high tide. Water temperature at the upper site was 2.8°C, at the lower, 3.0°C. Freshwater discharge from the pond was approximately 145 cubic feet per second. Consequently salt water was not detectable at the upper site. The dilution effect of the freshwater discharge was less at the lower planting site. There, salinities varied from 1.3‰ on the surface to 18‰ at the bottom (33 inches). On the next low tide salinities fell to 0 at the surface and to 0.01‰ on the bottom. Similar fluctuations occurred throughout each tidal cycle until ice cover prevented further observations. Accordingly, in respect to salinities, the introduced trout were presented with a variety of conditions varying from 0 to 18‰, as observed and probably higher (*see above*).

## Survival and Contribution of Planted Trout to Anglers' Catches

The angling season for brook trout on Prince Edward Island is April 15-September 15. No size limit is imposed. A creel census has been maintained annually on the Ellerslie System. The creel census taker has the primary duty to contact the anglers, to record catch, length and weight of trout, hours of fishing, and area of capture (stream, pond, estuary). Most of the fishing effort in Ellerslie Estuary is on pools at or near the head of tide.

The number and average fork length of planted trout caught at monthly intervals in 1962 are given in Table I. Survival of planted trout to the anglers' catches was 28 per cent. Anglers captured 848 brook trout, with a weight of 77.0 pounds, from the estuary. Planted trout contributed 65 per cent by number and 51 per cent by weight to this catch. (The total weight of 1,978 trout when planted on December 1, 1961, was 80.0 pounds; that of 553 planted trout when angled in 1962 was 38.9 pounds.) The total number of trout angled from the Ellerslie System (stream, pond, estuary) in 1962 was 2,085 with a combined weight of 199.1 pounds. Accordingly the planted trout made up 27 per cent by number and 20 per cent by weight of the overall catch.

A few planted trout survived the 1962 angling season in Ellerslie Estuary. Between 20 and 30 of these were observed in a pool near the head of tide after the close of the season. Planted trout could be consistently distinguished from native stock by a persistent lighter color. Five planted trout were captured at the counting-fence during the autumn. The capture of 28 per cent of the planted

trout by anglers, and the few observed after the close of the angling season, suggest that anglers effectively cropped the planted trout that were in the estuary.

TABLE I

Number and size of planted brook trout taken by anglers from Ellerslie Estuary during season following planting.

| | Number and average fork length in centimetres | | | |
|---|---|---|---|---|
| | Group A[1] | Length | Group B[2] | Length |
| Planted, Dec. 1, 1961 | 973 | 11.9 | 1,005 | 11.9 |
| Angled, 1962 | | | | |
| April 15-30 | 59 | 12.7 | 53 | 12.6 |
| May | 98 | 13.6 | 97 | 13.6 |
| June | 101 | 15.0 | 114 | 15.3 |
| July | 15 | 15.2 | 7 | 16.4 |
| August | 5 | 18.5 | 3 | 19.7 |
| September | 0 | — | 1 | 23.0 |
| Season total | 278 | | 275 | |
| % survival to anglers' catches | 28.6 | | 27.4 | |

[1] Planted at head of estuary in pool below dam (Figure 1).
[2] Planted in estuary 300 yd below dam (Figure 1).

Some planted trout may have left Ellerslie Estuary. Over a period of years (1947–1955), 10,142 native brook trout were tagged as they moved from Ellerslie Brook into the estuary (Smith and Saunders, 1958). Only 193 of these trout were reported angled, or otherwise captured, outside of the Ellerslie System. Some of the recaptures were made in a brook tributary to the lower part of Ellerslie Estuary. In the summer of 1962, a 100-yard lower section of this brook was electrofished. None of the 103 trout captured was from the 1961 planting in Ellerslie Estuary. Loss of planted trout by movement from Ellerslie Estuary to outside areas is judged to have been minor.

Winter estuarial conditions in 1961–62 were not unusual, but heavy and prolonged spates in April were the most extreme experienced in 17 years of observations on Ellerslie Brook. Planted trout, barred from moving up the stream by the dam, entered road ditches and other flooded areas at or near the head of tide. Sixty-two planted trout were salvaged from stranding as the water receded in these areas. Unassessed mortalities occurred. It is inferred that the planted trout met unusually adverse conditions and that otherwise the survival would have been greater than was actually realized.

*Comparison with previous plantings in the stream*

The survival to anglers' catches by the trout planted in the estuary may be compared with the results of six previous plantings in the brook (Table II). When hatchery-reared trout were introduced into the brook as fish of the year at a relatively small size (averaging about 6 centimetres in fork length), the survival to the anglers' catch was low, in average about 4 per cent. When intro-

duced as yearlings, and at a size comparable to that of the trout planted into the estuary, the survival to the anglers' catch of two plantings was 19.1 and 6.4 per cent, as against 28.6 and 27.4 per cent for the two groups planted into the estuary (Table I).

TABLE II

Survival of planted hatchery-reared brook trout to anglers' catches in Ellerslie Brook

| Origin of stock | Date planted | Average fork length (cm) | Number planted | Number angled | % survival to anglers' catches |
|---|---|---|---|---|---|
| Ellerslie Brook..... | Sept. 1, 1948 | 5.2 | 1,682 | 48(1949–52) | 2.9 |
| Eliot River..... | Sept. 1, 1948 | 5.6 | 1,638 | 23(1950–52) | 1.4 |
| Ellerslie Brook..... | Sept. 8, 1949 | 12.5 | 764 | 146(1949–52) | 19.1 |
| Eliot River..... | Sept. 8, 1949 | 12.5 | 915 | 59(1949–52) | 6.4 |
| Ellerslie Brook..... | Sept. 17, 1954 | 6.2 | 2,010 | 66(1955–58) | 3.3 |
| Howlan Stream..... | Sept. 17, 1954 | 6.7 | 2,010 | 152(1955–58) | 7.6 |

## Discussion

Anglers caught a higher percentage of trout from the estuarial plantings than from plantings made into Ellerslie Brook. The better returns from the estuarial plantings may have resulted, in part, from the lack of native trout in the estuary when the hatchery-reared trout were introduced. Native trout were present in good numbers at the times the earlier introductions were made into Ellerslie Brook. Previous studies have shown that brook trout, established in a stream habitat, have a competitive advantage over other native trout that were introduced into the same habitat (Saunders and Smith, 1962).

## Acknowledgments

The assistance in the field of Messrs. C. R. Hayes, Earl Coughlin and Cyril Williams, and in the laboratory of Miss Mary Holmes is gratefully acknowledged. Mr. W. S. Freeman, Officer-in-Charge, Cardigan Fish Culture Station, provided valuable assistance.

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# The Survival, Growth and Movement of *Esox masquinongy* Transplanted from Nogies Creek Sanctuary to Public Fishing Waters

*by*

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## Introduction

Conservationists in Ontario have been concerned for many years with the apparent decline in numbers of the maskinonge, or lunge (*Esox masquinongy*). A great deal of effort has been expended in artificial propagation with the aim of augmenting natural reproduction, and large numbers of fry and fingerlings have been planted throughout southern Ontario each year. In 1960, for example, approximately four million fry and fifty thousand fingerlings were reared at the provincial hatchery at Deer Lake and planted throughout the province. In view of the many natural enemies of juveniles, and since maskinonge do not normally reach maturity until the fifth or sixth year, there would appear to be merit in raising the fish to a larger size before planting. Elson (1940), experimenting with the planting of fry in a nursery area, obtained a minimum survival of 0.08% for the first year. The experiments were not, however, pursued.

In 1952 the transplanting of juvenile and adult maskinonge from Nogies Creek Sanctuary was begun, to determine their value in restocking public lakes. Although hatchery fingerlings were planted into the sanctuary from 1952 on (Muir, 1960), the bulk of the harvested fish were the result of natural reproduction by the resident population. It is noteworthy however, that the planted hatchery fingerlings displayed a survival rate (to age III) ranging from about three per cent to about ten per cent (unpublished). The present report deals with the survival, growth and movement, until time of recapture, of the fish transplanted from the sanctuary.

## Methods

Each fall since 1952, maskinonge have been netted and transplanted from Nogies Creek to the nearby public fishing waters of Pigeon and Sturgeon lakes. Some of the fish netted had already been tagged in previous spring periods, and the remainder were tagged prior to transplanting. The tag used was a numbered yellow plastic disc tag attached to the preopercular bone with nylon monofilament.

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The catches, held in twelve-foot retainer nets until transport, were normally transplanted the same day. Occasionally, on days when nets were moved or when the catch was small, the fish were held over in the retainers and transplanted the following day. The fish were transported in tanks approximately three feet in each dimension freshly filled with water to a depth of about two feet (approximately 115 imperial gallons). The number of fish per tank varied with the size and number of fish to be moved, and the distance travelled. In most cases, the trip was made in late afternoon and seldom exceeded thirty minutes so that no icing or aeration was required.

Since the operation seldom started before the first week of October, the newly transplanted fish were subjected to little angling before the close of the season on the 15th of that month. Thus angling pressure was not encountered until the following summer. Anglers were advised of the study and requested to return the tags (even from the sublegal fish) with pertinent information. A lucky draw, held at the close of each season, created interest among the anglers and publicized the study. Although an occasional report was received regarding tags not returned, it is believed that angler co-operation was good and that a high percentage of tags encountered was returned.

In two years, 1956 and 1959, maskinonge were not transplanted but were returned to the sanctuary for further study. Plantings subsequent to that time (not included in this report) have been followed by an intensive creel census to estimate the portion of tagged fish in the anglers' catch (Dursley and Fry, ms 1961).

## Habitat

Nogies Creek Sanctuary, as a maskinonge habitat, has been previously described (Crossman, 1956; Muir, 1960, 1963). Essentially, it is a five-mile stretch of river ending in an artificial lake of about 100 acres. The river portion is from 20 to 30 yards wide and from 4 to 12 feet deep. Crossman estimated the flow of water to be about 90 cubic feet per second in July. Although the speed of the current varies with the meandering of the river, it is always detectable. Standing and fallen dead trees are abundant on the drowned land portion and the entire area, except the actual river channel, supports dense growths of aquatic vegetation. A concrete dam at the lower end controls the water level and prevents immigration. Since only three tags have been recovered from fish that apparently escaped over the dam, it is believed that emigration is not significant. The ruins of a stone dam prevents emigration at the upper end.

Pigeon and Sturgeon lakes, separated by locks and control dam (Fig. 1), are part of the chain of lakes that form the Trent Canal System. Both lakes are fairly eutrophic and both contain large, shallow, weedy areas. Although no figures are available, Pigeon Lake appears to support larger populations of all the local game species. Residents report that both lakes have lost many of their weed beds during the last two decades but that Sturgeon Lake has changed more than Pigeon Lake. At present, Sturgeon Lake appears to be "less suitable", in the writer's opinion, for maskinonge than does Pigeon Lake. Such opinion is

admittedly biased, however, by the results recorded in this paper and by other observations, and is not founded on any objective evidence. The general flow of water approximately follows the long axis of both lakes. The volume of water passing through Bobcaygeon is estimated to be about 1200–1500 cubic feet per second during July and August and about 4500 cubic feet per second during the spring flooding. These estimates are derived from the 1960 to 1962 records of the Department of Transport for the major rivers entering Sturgeon Lake.

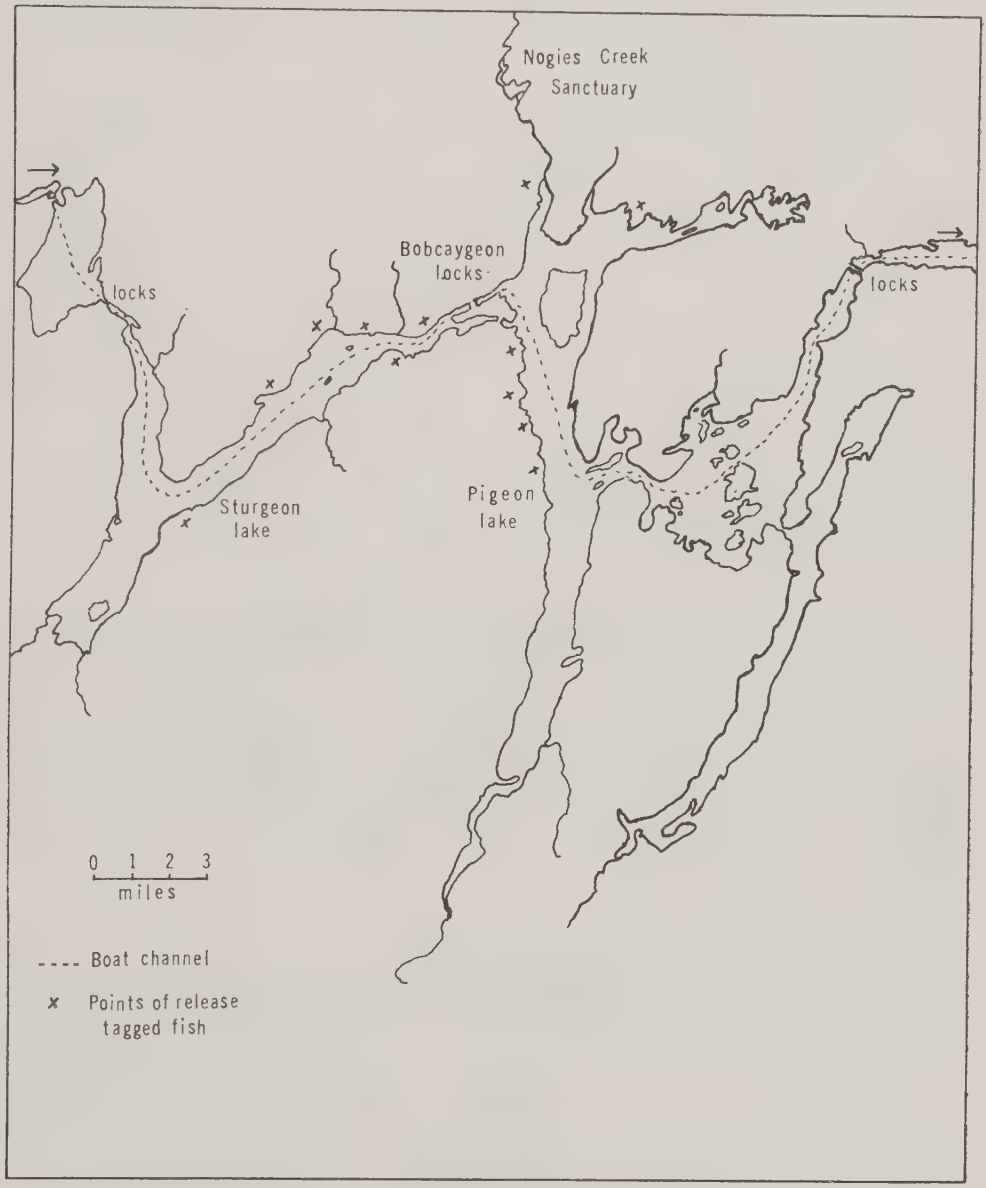


FIGURE 1. *Map of Pigeon and Sturgeon Lakes.*

## Transplanting and Tag Returns

During the month of October in the years 1952 to 1958 (excluding 1956) 1533 tagged and 520 untagged maskinonge were transplanted from Nogies Creek to Pigeon and Sturgeon lakes (*see* Table 1). A total of 227 of the tagged fish were reported caught by anglers by the close of the 1960 season, providing recapture rates of 14.7 per cent and 14.9 per cent of the fish planted into Pigeon and Sturgeon lakes respectively. However, of the 103 recaptures from fish planted in Sturgeon Lake, 32 (31.1%) had passed down into Pigeon Lake, either through the canal locks or over the dam. Since the apparent survival of fish planted into the two lakes is essentially the same, it is convenient to treat the two lakes as one system in so far as the recapture data are concerned.

The numbers of fish transplanted each year and the returns in subsequent years are shown in Table II. In all plantings, the largest number of tag returns was from the first year after planting (n+1) and no tags were returned after the fourth year (n+4). The data are rearranged in Table III to show the numbers of each age-group planted and subsequently recaptured. The percentage returned, by year of planting, ranges from 11.0 per cent for 1952 to 23.3 per cent for 1953, and by age, from 5.4 per cent for age-group II to 33.3 per cent for age-group IX. The progressive increase in recapture with age appears to be discontinuous, however, between ages IV and V (*see* Fig. 2) with a sharp increase from about 10 per cent to 20 per cent. The final column of Table III shows the percentage return, from the planting of each year, of fish age V and older at the time of planting. These figures range from 15.5 per cent to 31.6 per cent. The average length of fish from age-group V is approximately legal length (Muir, 1960) and these fish would presumably all be legal size during the angling season the following year.

The data are finally rearranged, in Table IV by age and by year of recapture. Of the 227 recaptures, 196 were caught in year n+1 (first season after planting) whereas only 29 were caught in subsequent years. The bottom row of Table IV shows the totals for fish age V and older. Of 757 releases, 142 were recaptured in n+1 and 17 in n+2. Consideration of the recapture of fish age IV and younger as seen in Table IV and Fig. 2, suggests that, unless a high rate of tag loss is affecting the recorded recapture rates, very few of these fish survive to contribute to the legal fishery. The following consideration of mortality will be confined to fish age V and older.

TABLE I

Numbers of tagged maskinonge transplanted to Pigeon and Sturgeon lakes (1952-1958) and the resulting recaptures (1953-1960).

| Lake | Number transplanted | Number recaptured | Percentage recaptured |
|---|---|---|---|
| Pigeon | 841 | 124 | 14.7 |
| Sturgeon | 692 | 103 | 14.9 |

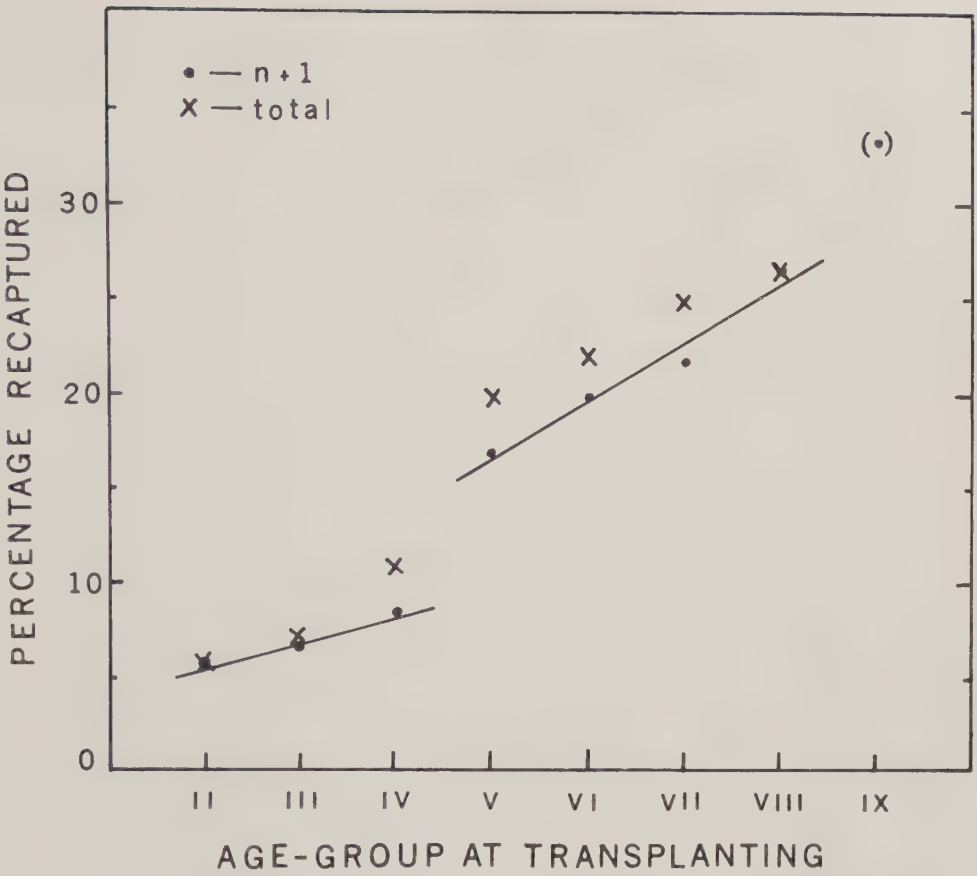


FIGURE 2. *The percentage of tags recaptured for each age-group at time of transplanting. Values are shown for the year following transplanting and for total recaptures. Plantings of 1952-1958.*

## TABLE II

The numbers of fish transplanted each year and the returns by year of recapture.

| Year of plant | Number planted | Total return | Year of return | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 |
| 1952 | 155 | 17 | 16 | 0 | 1 | | | | | |
| 1953 | 133 | 31 | | 26 | 4 | 1 | | | | |
| 1954 | 131 | 20 | | | 15 | 3 | 1 | 1 | | |
| 1955 | 298 | 53 | | | | 41 | 10 | 1 | 1 | |
| 1956 | — | — | | | | | | | | |
| 1957* | 323 | 43 | | | | | 1 | 39 | 3 | |
| 1958 | 493 | 63 | | | | | | 1 | 59 | 3 |
| Total | 1533 | 227 | 16 | 26 | 20 | 45 | 12 | 42 | 63 | 3 |

* 520 untagged fish were also transplanted in 1957.

## TABLE III

The number of maskinonge of each age-group transplanted from Nogies Creek in the years 1952 to 1958 and the subsequent recaptures. None transplanted in 1956.

| Year of plant | Data | Age at transplanting | | | | | | | | | | | | Total | Percent | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | XIV | | II+ | V+ |
| 1952 | planted | 3 | 17 | 60 | 39 | 27 | 9 | | | | | | | 155 | | |
| | captured | | 2 | 2 | 5 | 8 | | | | | | | | 17 | 11.0 | 17.3 |
| 1953 | planted | 1 | 13 | 44 | 56 | 18 | 1 | | | | | | | 133 | | |
| | captured | | 1 | 10 | 17 | 3 | | | | | | | | 31 | 23.3 | 26.7 |
| 1954 | planted | 2 | 16 | 49 | 32 | 24 | 4 | 2 | 0 | 1 | 1 | | | 131 | | |
| | captured | | | 9 | 6 | 4 | 1 | | | | | | | 20 | 15.3 | 17.2 |
| 1955 | planted | 5 | 43 | 82 | 94 | 48 | 16 | 5 | 1 | 1 | 2 | 1 | | 298 | | |
| | captured | | 2 | 6 | 20 | 15 | 8 | 2 | | | | | | 53 | 17.8 | 26.8 |
| 1957 | planted | 36 | 1 | 45 | 109 | 77 | 58 | 27 | 2 | 3 | 0 | 0 | 1 | 323 | | |
| | captured | | | | 10 | 13 | 12 | 7 | | | | | 1 | 43 | 13.3 | 15.5 |
| | untagged | 36 | 117 | 192 | 111 | 47 | 15 | 1 | 1 | | | | | (520) | | |
| 1958 | planted | 156 | 150 | 89 | 57 | 26 | 9 | 4 | 3 | | | | | 493 | | |
| | captured | 9 | 11 | 12 | 19 | 5 | 4 | 1 | 2 | | | | | 63 | 12.8 | 31.6 |
| Planted (tagged) | | 167 | 240 | 369 | 387 | 219 | 97 | 38 | 6 | 5 | 3 | 1 | 1 | 1533 | | |
| Recaptured | | 9 | 16 | 39 | 77 | 48 | 25 | 10 | 2 | 0 | 0 | 0 | 1 | 227 | | |
| Percentage | | 5.4 | 6.7 | 10.6 | 19.9 | 21.9 | 25.8 | 26.3 | 33.3 | | | | | | | |

## TABLE IV

Number of maskinonge planted at each age and the recaptures by year. Plantings of 1952-1958.

| Age at plant | Number planted | Year of recapture | | | | | Percentage | |
|---|---|---|---|---|---|---|---|---|
| | | n | n+1 | n+2 | n+3 | n+4 | n+1 | total |
| II | 167 | | 9 | | | | 5.4 | 5.4 |
| III | 240 | | 15 | | 1 | | 6.3 | 6.7 |
| IV | 369 | | 30 | 6 | 2 | 1 | 8.1 | 10.6 |
| V | 387 | 1 | 65 | 11 | | | 16.8 | 19.6 |
| VI | 219 | 1 | 43 | 3 | 1 | 1 | 19.6 | 21.9 |
| VII | 97 | | 21 | 3 | | | 21.6 | 24.7 |
| VIII | 38 | | 10 | | | | 26.3 | 26.3 |
| IX | 6 | | 2 | | | | 33.3 | 33.3 |
| X | 5 | | 0 | | | | | |
| XI | 3 | | 0 | | | | | |
| XII | 1 | | 0 | | | | | |
| XIV | 1 | | 0 | | | | | |
| Total | 1533 | 2 | 196 | 23 | 4 | 2 | | |
| Total V+ | 757 | 2 | 142 | 17 | 1 | 1 | | |

The first estimate of the average rate of exploitation of fish age V and older is 142/757 = 0.188, which means that 19 per cent of the fish transplanted were caught in year n+1. This in itself is minimum since a portion of the fish may have died as a result of the transplanting and others may have lost tags. However even if these portions were known, the estimate would be the exploitation of fish eight months after transplanting during which time "ordinary" natural mortality would have taken its toll.

It is of more interest to know the rate of exploitation of tagged fish, during the actual fishing season, which are present at the beginning of that season. For this, we need an estimate of the loss of tags or tagged fish during the eight months between planting and the start of the fishing season. The fishing season extends from July 1st to October 15th, a period of $3\frac{1}{2}$ months. However, since the greatest amount of fishing occurs during July and August and relatively little after mid-September, we shall consider the season to be of only $2\frac{1}{2}$ months' duration.

An estimate of the loss during the first eight months may be approached by first estimating the rate of natural mortality for the interval beginning with the start of fishing in n+1 (July 1st) and ending at the same point in n+2. This mortality rate could be applied to the period from transplanting to the start of fishing provided the following assumptions are reasonably met.

1. That natural mortality occurs at a uniform rate throughout the entire year and is similar for the various age-groups involved.
2. That whatever tag loss or mortality due to the tag exists, occurs at a uniform rate throughout the period of study.
3. That the catchability of the tagged fish is uniform, so that the catches in n+1 and n+2 are approximations of relative abundance.

Taking the catches of 142 and 17 to represent abundance of tagged fish, near the middle of the fishing season in n+1 and n+2, we may use the "catch curve method" (Ricker, 1958, pg. 44) to estimate total mortality during the interval. During this one-year period the total disappearance of tags (i.e. apparent total mortality, á) is 0.88. The second of the above assumptions, that of tag loss, is probably the most important in this particular study (Muir, 1963). Within the sanctuary, the rate of tag loss increases with time in violation of the assumption. Since this would tend to increase the apparent mortality, the estimate of á = 0.88 is probably a maximum. Since the heaviest loss due to mortality caused by tagging and handling would occur well in advance of the start of the first fishing season, it does not likely influence this estimate.

A conditional disappearance of 0.88 corresponds to an instantaneous rate of disappearance (i′) of 2.12 which can be fractionated

$$i' = p + q' = 2.12 \tag{1}$$

where p is the instantaneous rate of fishing mortality and q′ designates the instantaneous rate of loss due to natural mortality (q) plus tag loss and the additional mortality imposed by the tag. The basic notation i, p, and q, is that of Ricker (1958) and the symbols correspond to Z, F, and M of the "International Notation" (Holt *et al*, 1959).

The problem of separating i′ into its components may be approached by considering the period of 8 months between the period of release and the start of the fishing season and then the period of $2\frac{1}{2}$ months for the fishing season itself. We must assume, however, that the estimate for disappearance of 0.88 which was derived from the 12-month period between the start of fishing in n+1 and in n+2, also applies to the 12-month period immediately following the transplanting in year n. Thus after 8 months the survivors of a unit number of tagged fish are:

$$e^{-8q'/12} \tag{2}$$

During the fishing season the fraction caught, of those present at its start (i.e. of those represented by expression (2)) is shown by the expression (which is analogous to pa/i):

$$p\,\frac{(1-e^{-(p\,+\,2.5q'/12)})}{p + 2.5q'/12} \tag{3}$$

The product of (2) times (3) is the fraction of the number tagged and released that are caught in the first fishing season and corresponds to 142/757 = 0.188 from above.

Thus,

$$p\,\frac{(1-e^{-(p\,+\,.208q')})}{p + .208q'} \cdot e^{-.667q'} \tag{4}$$

is solved by taking trial values of p, obtaining the corresponding q′ from (1) and comparing the computed product with 0.188. The final values, obtained in this manner, are p = 0.75 and q′ = 1.37 (which sum to 2.12 of (1)). These coefficients

correspond to conditional mortality rates of 0.53 for fishing and 0.75 for the other causes, the total disappearance still remaining 0.88. The estimate of fishing mortality is probably low since some of the fish which had lost tags would survive to be caught although not recognized.

The estimate of exploitation during the fishing season is given by expression (3). For a p value of 0.75, the rate of exploitation (u) is 0.47, which is the fraction of the tagged fish estimated to be present at the beginning of the fishing season which were actually caught during the season. Of 757 transplanted fish, only 303 remained with tags when the season opened in n+1 and 142 (47%) of these were caught.

Although these estimates are close to the best that can be made from the data, they must be considered with great caution. The first estimate of exploitation (0.19) is certainly too low since many fish must have died or lost tags during the 8 months between transplanting and the fishing season. The second estimate (0.47) is probably high for several reasons. The basic estimate, 0.88 for total mortality between n+1 and n+2, was considered to be maximum and the extrapolation from this period to the one following the transplanting could involve very serious errors. In view of the high mortality during the season following tagging, observed within the sanctuary (Muir, 1963) it is probable that the true exploitation falls at least mid-way between these two—of the order of 0.35 or greater.

## Growth of Transplanted Fish

Anglers were requested to report the length of tagged fish at the time of recapture. From the transplantings of 1953, 1955, 1957 and 1958, 121 lengths were reported in year n+1 and 19 in n+2 for fish in age-group IV to VIII at the time of planting. Most measurements reported appeared credible, but a few indicated exceptional growth and a few were less than the length recorded at the time of transplanting. Under such circumstances, it is probably more advisable to use all measurements reported than to subjectively eliminate those that appear to be out of line.

Recaptures were made during the period from July 1st to October 15th. The measurements were therefore taken throughout the major part of the growth season, and the average increments, calculated from the measurements returned by anglers, will be something less than the true increments for the entire growing season. How much less, however, can not be determined from the available data.

The average growth increments for fish recaptured in year n+1 are shown in Table V for age-group V to IX (in year n+1). These increments are plotted in Fig. 3 together with the increments determined for tagged and untagged fish in the sanctuary during the growing season of 1957 (Muir, 1960). From the figure it is apparent that the partial growth increment for tagged fish transplanted to the larger lakes was greater than the increment during 1957 for tagged fish returned to the sanctuary, but still less than that for untagged fish in the sanctuary.

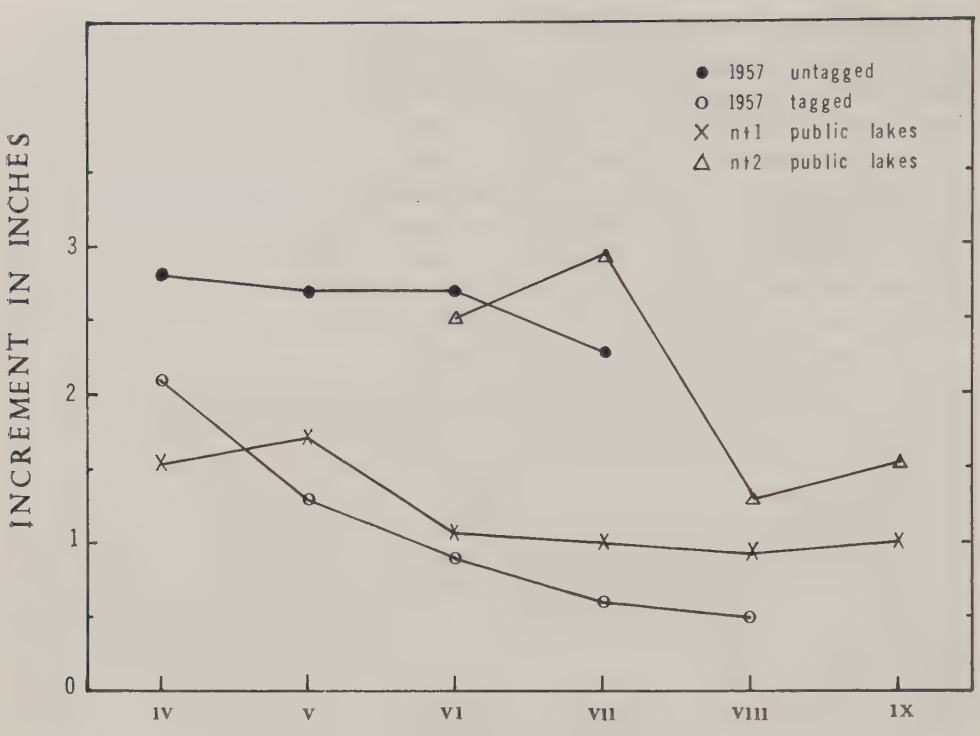


FIGURE 3. *Annual growth increments. Values for the 1957 tagged and untagged increments in Nogies Creek are taken from Muir (1960), and for the public lakes, derived from data returned by anglers. The increment for n+2 was obtained by subtracting the appropriate n+1 increment from the 2-year increment observed in n+2.*

## TABLE V

Growth increments (inches) for each age, estimated from lengths reported by anglers. Measurements were taken during the growing season so that the increments represent less than a full year. One-year increments for n+2 obtained by subtracting the increment in n+1 for the appropriate age-group.

| | Age-group in year of recapture | | | | | |
|---|---|---|---|---|---|---|
| | IV | V | VI | VII | VIII | IX |
| *Year n+1* | | | | | | |
| Number | 11 | 18 | 52 | 27 | 17 | 7 |
| Increment | 1.5 | 1.7 | 1.1 | 1.0 | 0.9 | 1.0 |
| *Year n+2* | | | | | | |
| Number | | | 5 | 9 | 3 | 2 |
| Increment (2 yr) | | | 4.2 | 4.0 | 2.3 | 2.5 |
| (n+2) − (n+1) | | | 2.5 | 2.9 | 1.3 | 1.6 |

The growth increments for the second year after tagging (n+2) for 19 fish are also shown in Table V and Fig. 3. The increment for the second season was determined by subtracting the increment observed in n+1 from the two year increment observed in n+2, adjusting for increased age. The plotted data suggest that growth during the second year was greater and more nearly normal than during the first year after tagging.

This appears to be contrary to an earlier statement (Muir, 1960) that "the few measurements available after the second season (within the sanctuary) indicate that normal growth was not resumed". In both cases however, the data for the second year are certainly too few to give a reliable picture.

If the average increments determined from the anglers' measurements are reliable, which their consistency (Fig. 3) seems to suggest, then it would appear that the tagged fish, at least, attain a greater length in the larger lakes than in Nogies Creek. It remains to obtain a tag which does not interfere with the growth, to determine whether the slower growing Nogies Creek fish will attain lengths comparable to those native to the larger lakes.

## Movement

Of the reports returned by anglers, 144 (from year n+1) included points of recapture that could be located on the map. The distance between the points of release and recapture represents the minimum distance travelled during the interval. From the examination of the direction and distances moved, four categories were established, as follows:

*Less than one half mile*—fish recaptured at or near the point of release.

*Across*—fish recaptured at some point greater than one half mile from release, but in a direction that could not be considered to be in the next two categories.

*Downstream*—movement greater than one half mile, considered to be in the same general direction as the flow of water through the system.

*Upstream*—movement greater than one half mile, considered to be opposite to the general flow or into the mouth of one of the many streams and rivers entering the system.

Reference to Fig. 1 indicates that many directions of movement are possible for which such categorization is almost arbitrary. The definitions were followed as closely as possible however, and the number of fish in each category and each age-group are shown in Table VI. None of the categories used indicates a trend in the direction moved. Of the 144, 55 (39%) moved less than one half mile or in the across direction, 44 moved in a general downstream direction and 45 moved upstream. Of the 44 that moved downstream however, 26 (59%) passed through the locks or over the dam from Sturgeon to Pigeon Lake and most of these were caught in the river below the dam. Had they been able to re-enter Sturgeon Lake, their observed net movement could well have been upstream. A total of 98, of the 144 fish, were recaptured in rivers or at river mouths, indicating a strong

preference for moving water. Such preference may be related to the river condition of the sanctuary, since in localities such as the Bobcaygeon River, between Pigeon and Sturgeon lakes, tagged maskinonge are apparently caught out of proportion with untagged fish.

The average distances travelled for fish of each age group are shown in the final row of Table VI. The values in parentheses, for age-groups IV and VII, are exclusive of two fish that travelled extraordinary distances (23 miles downstream each). With the exclusion of these two fish, the average distance travelled increases with age from 1.8 miles for age-group III to 2.7 miles for age-group VII. A similar increase in the distance travelled with age was observed for maskinonge within the sanctuary (Muir, 1963).

The distance between point of release and point of recapture gives little indication, however, of the nature of the movement since the time out involved was nearly one year. Reports are quite common of particularly large fish apparently being seen in the same location for several days or even weeks, and many anglers believe that "lunge" tend to remain in "home territories". The significance of the recapture of so many tags in Pigeon Lake, that were planted into Sturgeon Lake, is not clear. It is questionable that it represents selection on the part of the fish. If movement in the reverse direction were not so difficult, the significance might be more apparent. Two reports were received of Pigeon Lake tags being caught in the upper lake but in both cases the information was not complete enough to include in the above table. Fish are occasionally observed in the locks at Bobcaygeon, providing the only natural explanation for the upward movement, and probably accounting for part or all of the downward movement.

TABLE VI

Direction, average distance moved and number of each age-group determined at point of recapture in year n+1. Figures in parentheses exclude two fish that moved extraordinary distances. Read table, for example, five fish from age-group III moved across an average of 1.8 miles. See text for explanation of categories of movement.

| Movement | Age-group at planting | | | | | | |
|---|---|---|---|---|---|---|---|
| | III | IV | V | VI | VII | Number | Average |
| Less than ½ mile | 2 | 4 | 7 | 12 | 5 | 30 | — |
| Across | 1.8/5 | 1.8/4 | 2.4/11 | 2.3/3 | 3.2/2 | 25 | 2.2 |
| Downstream | 2.0/1 | 4.9/10* | 2.3/18 | 3.8/9 | 8.5/6* | 44 | 3.9(2.9) |
| Upstream | 2.8/4 | 3.6/5 | 3.3/20 | 4.4/13 | 4.6/3 | 45 | 3.7 |
| Total number | 12 | 23 | 56 | 37 | 16 | 144 | |
| Average distance | 1.8 | 3.2(2.3) | 2.4 | 2.7 | 3.9(2.7) | | |

* Two fish, age IV and VII, moved 23 miles downstream each and are excluded from the values in parentheses.

## Discussion

A reasonable objection to any transplanting program is the indeterminable danger of upsetting the natural balance in the new lake. In certain situations however, where the production of fish is limited by adverse conditions during a particular stage of the life history, there may be justification for planting fish of a size greater than that of the critical stage.

In the present study, it was hoped to learn whether transplanted juvenile and adult maskinonge would survive to significantly contribute to the existing fishery. The movement study provides little information on the behaviour of the transplanted fish since no comparable data are available for the native fish. The distances moved however, do not appear unduly great as might be expected if the fish could not find suitable habitat. Furthermore, the growth of tagged fish suggests that the public lakes provided conditions that were at least better for growth than Nogies Creek.

Tagged fish were watched for during the 1959 spawning observations in Pigeon Lake. No tags were seen at the time but one lone fish evidently cruised through the field of the underwater camera and was later recognized when the film was viewed. Although active spawning was taking place in the immediate vicinity, it is unknown whether this tagged fish actually spawned. It is quite probable however, that the transplanted fish do contribute to the spawning stock.

The low percentage return of fish younger than age-group V suggests that, unless an extremely large number of tags are lost during the second year, these sub-adult fish do not survive in sufficient numbers to warrant transplanting. Of the adult-sized fish (age-group V and older), 21.5 per cent of the tags were subsequently reported by anglers. Allowing for tags not reported and for tags lost, this figure might be placed as high as 30 per cent for an average utilization of adult fish. This could still be low however, since tagging undoubtedly causes additional mortality that would not be present if untagged fish were transplanted on a management basis. Such utilization of the harvested crop of adult fish from Nogies Creek Sanctuary is inefficient compared to allowing the anglers direct access to the sanctuary.

In defense of such inefficient practices, it should be pointed out that Nogies Creek is a small area with a high catch-per-unit-of-effort (experimental angling), whereas the nearby public lakes are large with a high angling pressure and a low catch-per-unit-of-effort. If the sanctuary were opened, it would be quickly exploited by a few anglers and much damage would be done to the concentrated juveniles. Transplanting, although it decreases the utilization, spreads the additional catch over the entire angling population.

The final phase of the study, presently being conducted, will provide estimates of the rate of tag loss and mortality of the tagged fish and of the portion of the total catch contributed by the transplanted fish.

## Acknowledgments

This study was carried on as part of a joint project with financial assistance and direction from the University of Toronto, the Ontario Department of Lands and Forests, and the Toronto Anglers' and Hunters' Association. Appreciation is expressed for the guidance of Dr. F. E. J. Fry, chairman of the project committee, and for the assistance of several undergraduate students and employees of the Ontario Department of Lands and Forests. Dr. W. E. Ricker provided helpful suggestions concerning the section on mortalities.

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# A Retractable Transducer for Small Boat Echo Sounding

*by*

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A program of generalized lake investigation was begun on the island of Newfoundland in 1961. An important part of each lake survey was the determination of depth distribution. Due to the limited time that could be spent on any water, it was decided that these data would be obtained by echo recorder and a suitable model was acquired. The problem arose as to how best to install this equipment, especially the transducer, in a small boat.

The usual type of transducer installation through the boat bottom did not at first seem desirable because this would leave it exposed to damage from the lake shore when beaching, or from flying stones when trailering over unpaved roads. Consideration was therefore given to an "outrigger" mounting similar to that described by Stroud and Grice (1952), or Saila and Horton (1957), and a modified side rig was constructed. It did not seem especially suited for the planned surveys since it rather "cluttered up" the boat for other operations such as experimental netting. It was decided, therefore, to attempt to design something more suitable to our requirements.

The obvious alternative to a transducer mounted over the side or stern of the boat was one mounted inboard. This, however, raised the probability of transducer damage referred to earlier. It was overcome by designing a metal housing into which the transducer could be retracted for protection when the boat was being landed or moved by trailer. This housing is described in this report in the event that such an arrangement might prove helpful elsewhere.

The boat in which the sounding unit was mounted was a 16-ft. moulded plywood model having a 64-inch beam and a depth of 30 inches. It was a "production" model from a well known manufacturer (Fig. 1), and was powered by an outboard motor. Speed of travel during soundings varied with the size of the lake being covered. On very large lakes, long transects could be run at full speed (about 15 m.p.h.). Shorter transects on smaller lakes were run at slower speeds.

The recording unit, a Bendix DR-19, was a battery powered transistorized model. It was mounted just under the foredeck where it could be easily read by

FIGURE 1. *Lake survey boat in which depth recorder and transducer housing was installed. The transducer shaft, in the "up" position, may be seen to the right of the center photo behind the forward seat backrest. Department of Fisheries photo.*

the "driver" and was also protected from the elements (Fig. 2). It was connected to the transducer and the power supply by the usual means.

The transducer housing, which made retraction possible, was constructed by a local machine shop and no particular difficulties were experienced in this regard. Cost, exclusive of installation (carried out by our technicians), was about $125.00.

Figs. 3 and 4 show the design of this equipment together with necessary detail for construction. All construction was of brass or bronze. Dimensions could be altered to suit varying boat or equipment requirements.

The transducer housing consists basically of a lower cylinder, about 6 inches in diameter and 8 inches high, the lower (open) end of which is installed through the boat bottom and secured by inside and outside flanges. Attached to the top of this cylinder, which is otherwise closed, is a hollow brass tube, approximately $16\frac{3}{4}$ inches in length, which receives a brass shaft attached to the transducer stem. The diameter of the tube is such as to provide a "sliding fit" for the transducer shaft (Fig. 3). The transducer itself is fitted into a circular brass plate of

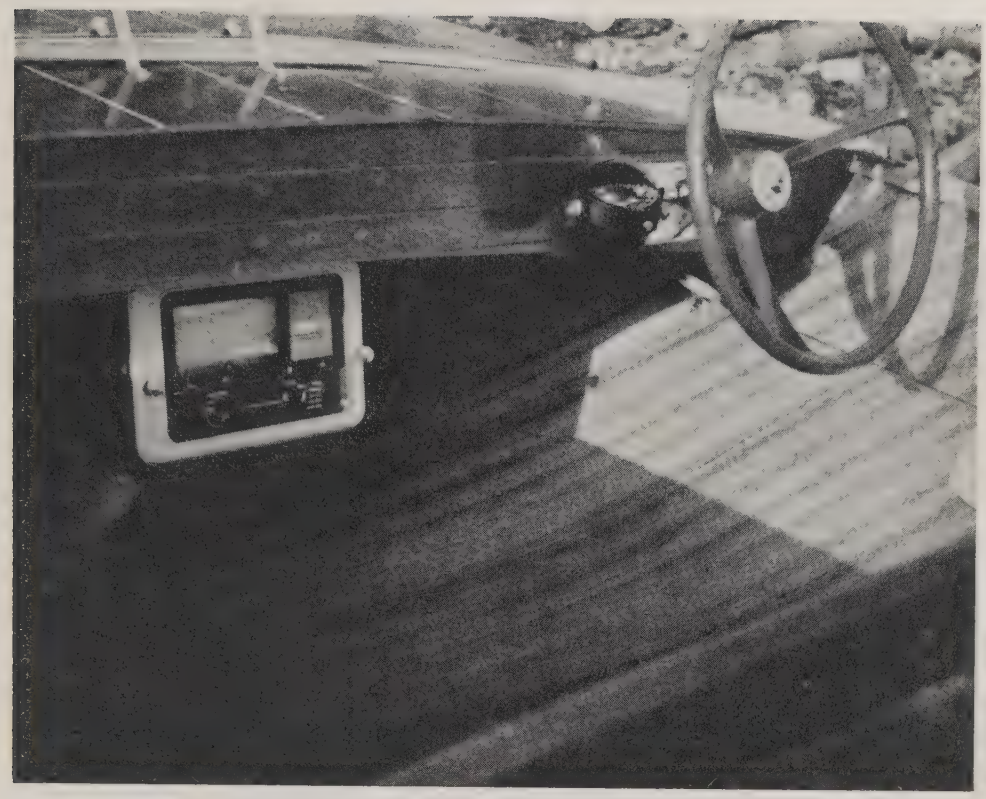

FIGURE 2. *The recording unit mounted under the foredeck of the lake survey boat. Department of Fisheries photo.*

the same diameter as the inside of the lower cylinder (Figs. 3 and 4). When attached to the shaft, and inserted in the housing, this assembly can be retracted about 6 inches into the lower cylinder. This is done for beaching and trailering the boat to prevent damage, or for any other reason when the recording equipment is not required for operation. The housing itself is permanently mounted in the boat (Fig. 5) but, if the recorder is not to be used for lengthy periods of time, the transducer assembly may be withdrawn through the bottom opening.

The "collar" (Figs. 3A and 4E) attached to the shaft is adjusted so that when the transducer assembly is lowered the transducer itself is exactly flush with the bottom of the boat (Fig. 6). The knurled and threaded ring is slacked or tightened to facilitate raising or lowering of the assembly. The drill hole in the shaft is for the "up" (retracted) position and a pin is passed through it to ensure that the transducer can not be accidentally lowered.

The apparatus described has been used during three field seasons and although the usual operating problems were experienced none were attributable to the transducer housing. This modification of the transducer assembly has been a great convenience at all times and a worthwhile aid to the lake survey program.

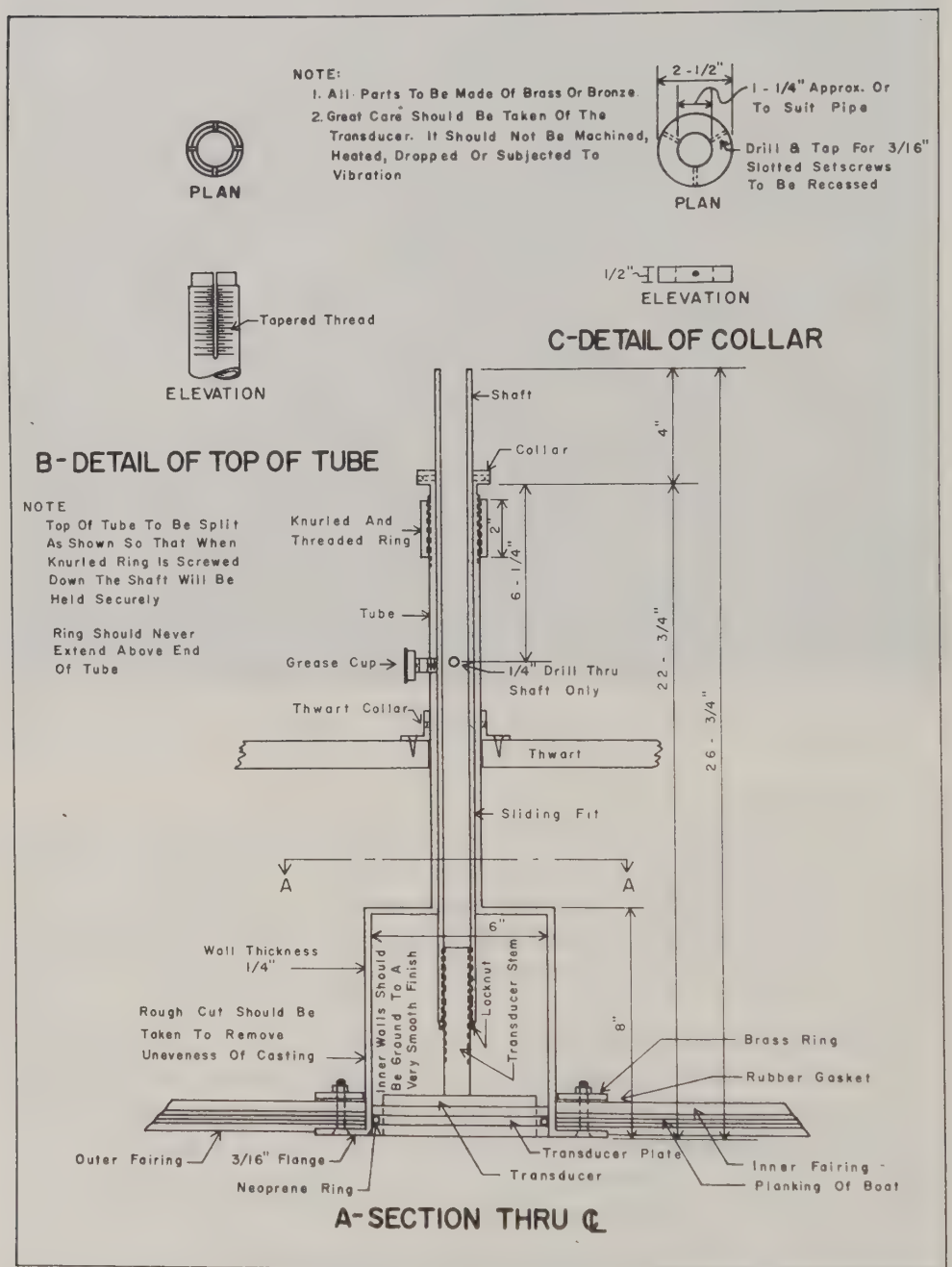


FIGURE 3. *A vertical cross section through the installed transducer housing showing construction and assembly detail.*

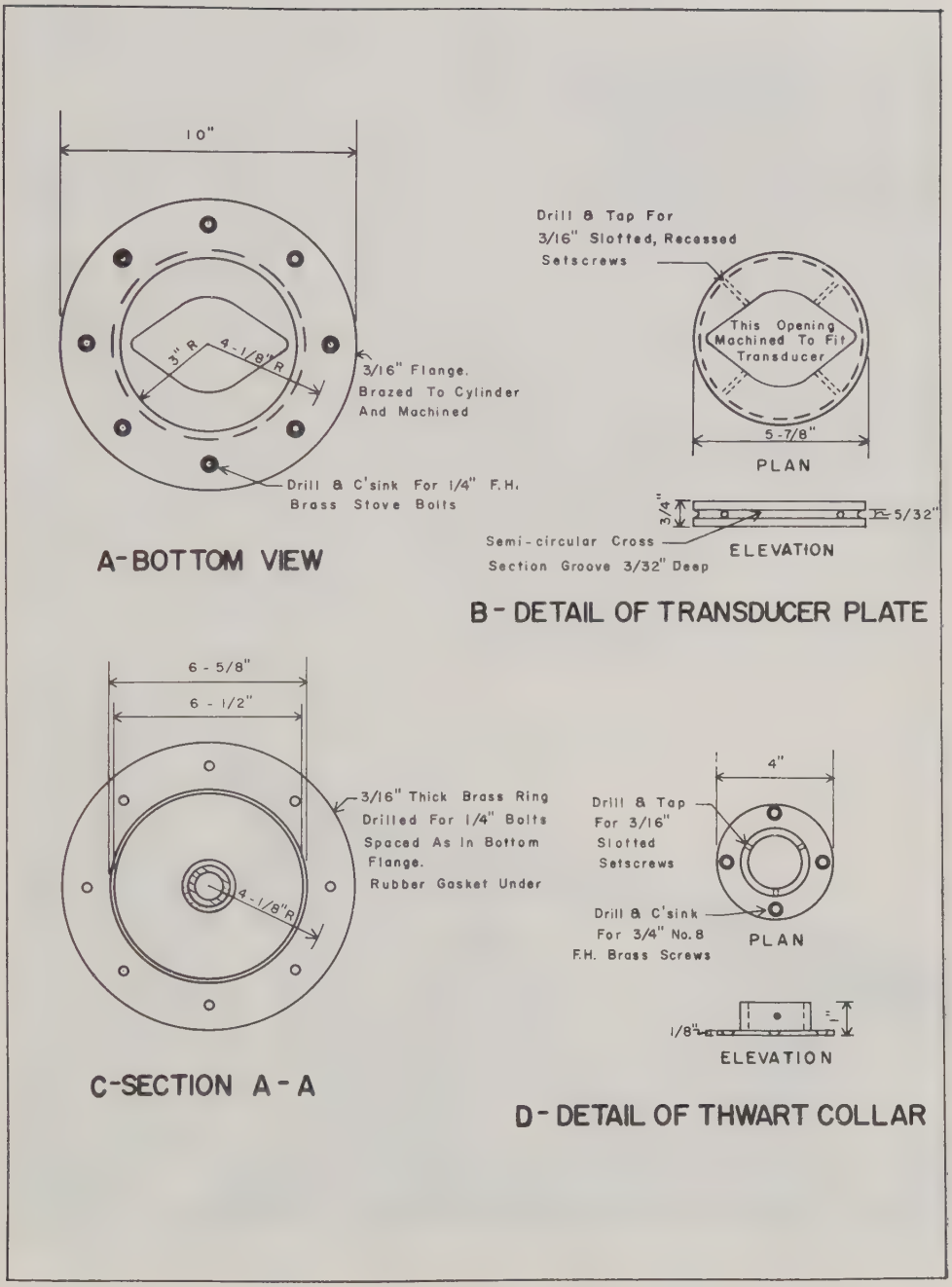


FIGURE 4. *Cross section through A-A (Fig. 3) together with detail of transducer plate assembly and thwart collar.*

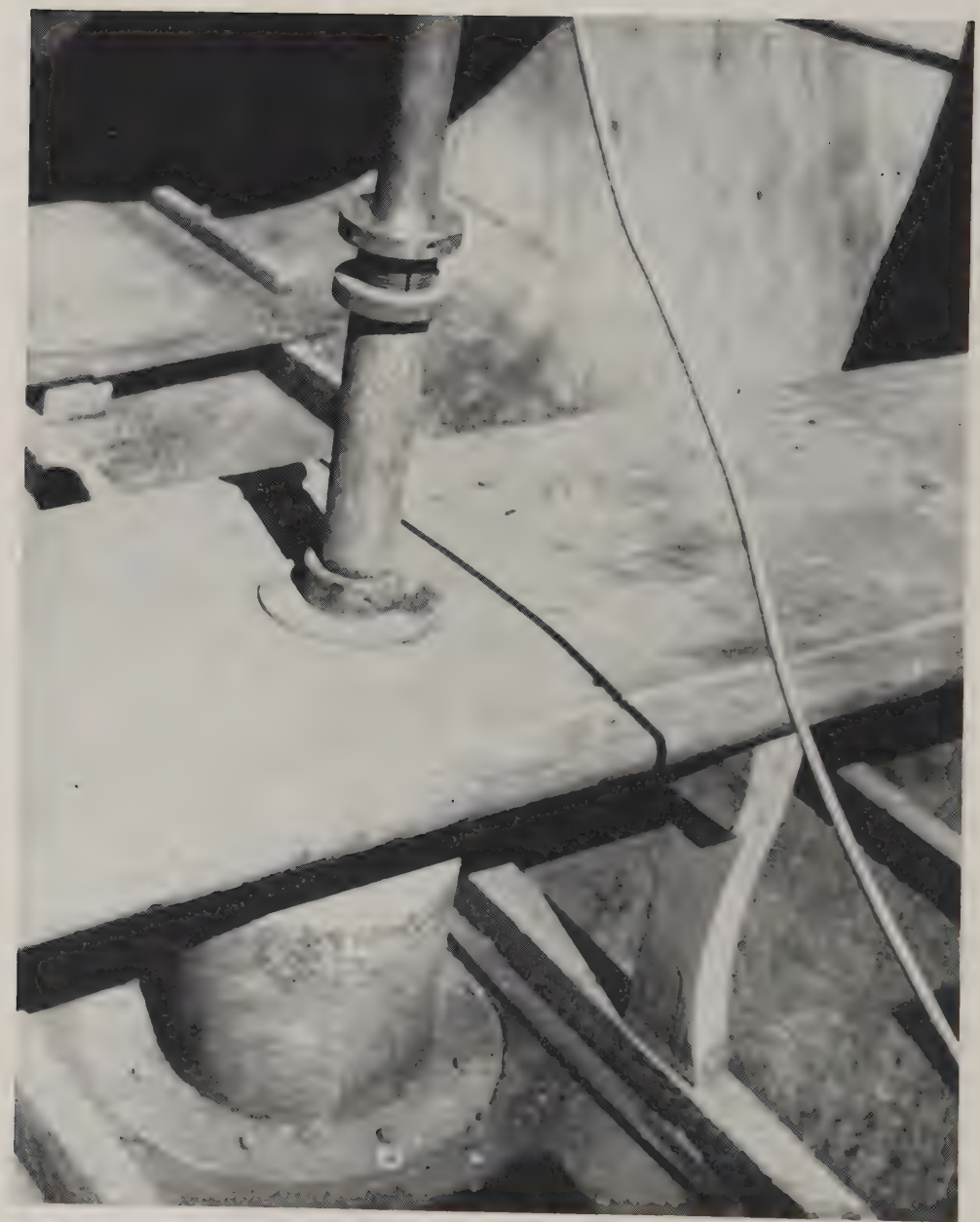

FIGURE 5. *Photo of the transducer housing installed in operating position in the boat. The insulated wire seen in the photo links the recording unit and the transducer. Department of Fisheries photo.*

FIGURE 6. *View of the boat bottom showing the transducer plate assembly with the transducer in the "down" or operating position. The outside flange, referred to in the text, is covered by a fibreglass "fairing". In this picture the fibreglass material is considerably worn and requires repairs. Department of Fisheries photo.*

## Acknowledgments

Several members of the staff of the Fish Culture Development Branch in the Newfoundland area contributed to the final design of the transducer housing described. Detailed construction plans were drafted by our engineering section, amongst whom particular acknowledgment is due Engineer B. R. Bauld and Technician T. P. Carew.

Field operation was mainly by Biologist W. D. Seabrook who used this equipment for the greater part of two field seasons of lake investigation. Our indebtedness to these and other staff members is gratefully acknowledged.

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# A False Weir Fishtrap

*by*

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## Abstract

This report describes a new fishtrap installation that was designed for the Stamp Falls Fishway for the purpose of trapping coho and spring salmon for transplant into the Robertson Creek Spawning Channel.

Fish are attracted to an artificial waterfall and jump into an anaesthetic pool where they can be taken out for inspection, tagging or transportation for transplant. The principle of the false waterfall has been used on at least one previous occasion in connection with fish trapping. This was at the Trinity River facilities operated by the California Department of Fish and Game under agreement with the United States Bureau of Reclamation.

## Introduction

The Stamp Falls Fishway is located on the Stamp River which is part of the Somass River System on Vancouver Island, British Columbia. It is a "vertical slot" type fishway with pools 10 feet wide by 10 feet long, and overcomes a maximum surface drop of 37 feet. Because of limited space and to produce a more compact structure, the fishway folds back on itself. It is in the upstream fold that the trap was installed. This location was chosen because it gives the largest single compartment in which to work and the highest head differential for the attraction water supply.

## Description of Trap—(Fig. 1)

The trap consists of a 3/4-inch plywood box 8 ft. 6 ins. long, 6 ft. 10 ins. high and 3 ft. 10½ ins. wide. The box has a double floor, and double front and back walls. It was designed to fulfil two functions:

1. To hold an anaesthetic solution in an open watertight tank.
2. To create a "false waterfall".

The anaesthetic tank (4) holds 425 Imp. gal. of water at a depth of 3 ft. 6 ins. The inside of the tank received three coats of resin and the corners are fibreglass reinforced to make it watertight. A small 1/2 inch x 3/4-inch gutter (3) is mounted 3 inches below the top of the front wall to collect any backspill from the false waterfall (1) and thus prevent dilution of the anaesthetic solution.

The double back wall (6), the double floor (5) and the double front wall (2) form a U-shaped rectangular conduit open at each end. One end receives the

attraction water (9), while the other forms the free overflow or "false waterfall" (1). The double back wall (6) is built up two feet above spill elevation. One side has an opening which is fitted with a small head control gate (8). By spilling surplus attraction water over the gate a constant head and steady flow in the attraction system is maintained. A hinged baffle within the double front wall (2) makes it possible to adjust the width of the discharging opening permitting adjustments to the shape of the waterfall (1) and the discharge velocity.

The trap is suspended on cables from four winches. To reduce buoyancy of the trap, a layer of concrete blocks was placed on the floor of the tank. It took 67 man-hours to fabricate the trap. The cost of the materials totalled $144.00.

## Installation and Operation of Trap

For the operation of the fishtrap a water supply of 2 to 4 cfs with a minimum head of 1.5 to 2 feet is required. As the depth of flow within the fishway varies from 2 to 16 feet, depending on river discharge, the trapping facilities were located in an area where maximum head could be obtained. (Fig. 1, Section a).

An 18-inch diameter slide gate (10) installed in the fishway wall controls the water supply. The gate was fitted with an 18-inch diameter metal elbow (11) which discharges the attraction water in a free fall into the conduit through an oversized plastic hose (12).

To create a holding area and permit a steady fishway flow, a floor diffuser was installed downstream of the trap. On one occasion in the past a V-trap without a diffuser was used to trap fish. The operation of the trap caused flow fluctuations within the fishway. Upstream migrants "panicked", dropped back, and delayed further ascent. In the present trap less than 5 per cent of the flow is used for the fishtrap operation, leaving a steady flow of more than 95 per cent passing through the diffuser and fishway at all times.

The diffuser (13) was installed in an inclined plane to permit a deep area for holding and a more shallow one to allow added attraction below the "fall". A vertical grating panel (14) was installed under the inclined panel on the upstream side. This panel prevents fish from dropping back under the diffuser, and also collects all floating debris.

For access into the fishway a stepladder (15) was bolted to the fishway wall. The ladder leads to a floating walkway (16), located along the fishtrap. A heavy timber column (17) with stoplog guides on either side divides one section of the fishway into two openings. One leads to the fishtrap. The other is equipped with a fish passage gate (18). When the trap is not in operation the gate (18) is opened and fish are permitted to bypass the trap and migrate freely through the fishway. A timber structure above the fishway (not shown in Fig. 1) is equipped with a monorail and hoist.

In operation, fish ascend the fishway until they reach the diffusion chamber. When the trap is in operation the fish passage gate (18) is closed and the only open migration route is over the false waterfall (Fig. 2), into the anaesthetic tank. From here the anaesthetized fish are manually placed in a stretcher-type hopper and lifted into a tank truck for transportation to the Robertson Creek Spawning Channel.

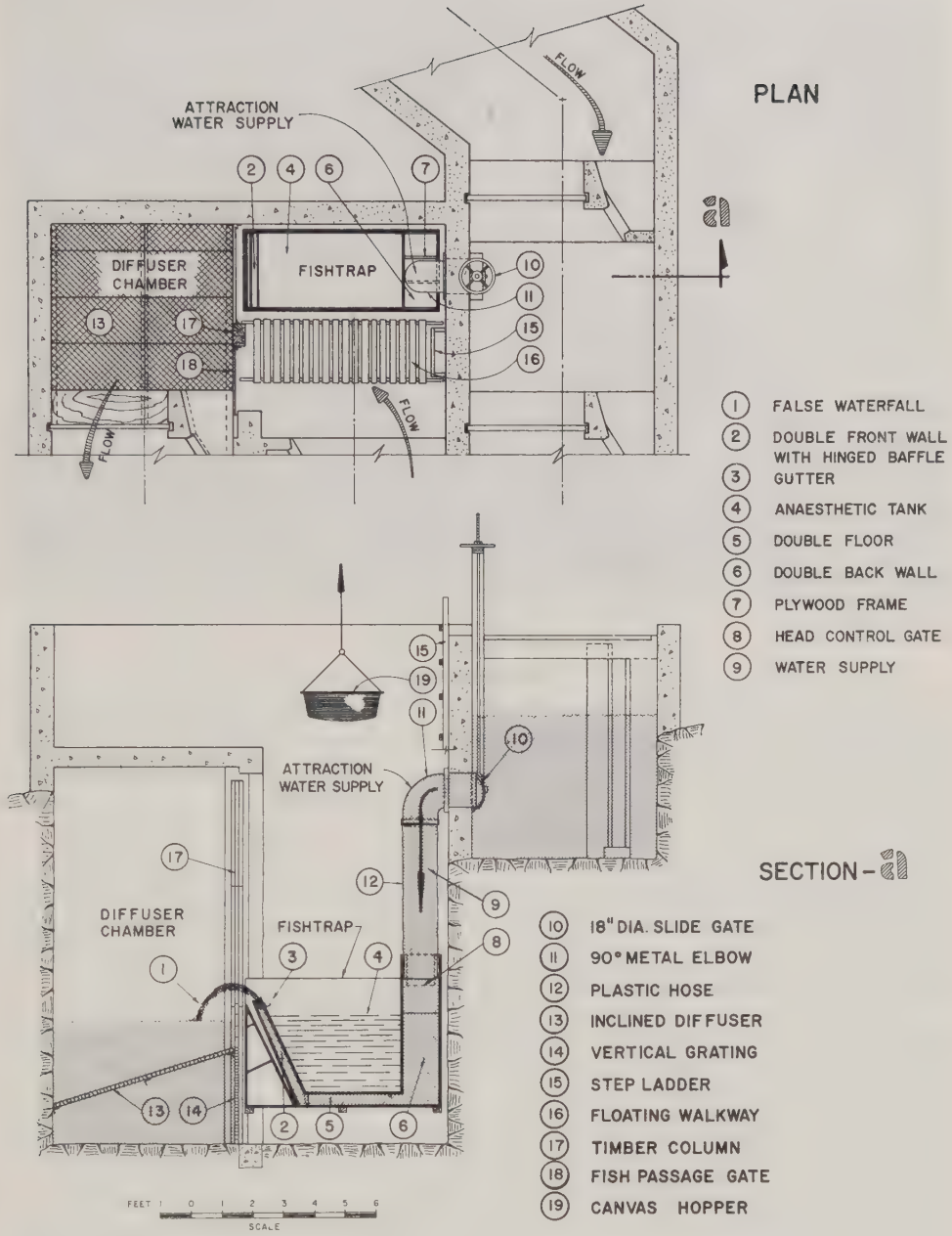


FIG. 1 TRAP INSTALLATION IN STAMP FALLS FISHWAY

FIGURE 2. *Salmon ascending false waterfall.*

The trapping facilities at the Stamp Falls fishway were operational in 1963 from September 15th until October 13th, when record rainfalls caused exceptionally high water levels and made it impossible to continue the operation. Ascending the fishway during this period were pink, sockeye, coho and chinook salmon and steelhead trout. The fishway was kept open most of the time to permit unobstructed migration for the pink and sockeye salmon. Only when large numbers of coho were present was the trap activated. On October 4th 30 cohos were trapped in less than five minutes after activating the trap and on October 6th over 200 salmon were trapped within five hours. Salmon were jumping into the anaesthetic pool of the trap while anaesthetized fish were being removed. On those days salmon were attracted into the trap with no apparent delay or resistance.

There were, however, days when salmon would make up to seven attempts before successfully completing a jump. The difference in behaviour appeared to be related to such factors as the time of day, the number of fish present in the diffuser chamber, and water temperature and discharge. A further very important factor is the shape of the "false waterfall"; that is, the thickness and angle of inclination of the jet and the height of the fall.

It was found that a high velocity discharge with a thin jet and high fall (Fig. 3*a*) is far less effective to attract fish than a low velocity, thick jet with a low fall (Fig. 3*b*). A further improvement in fish attraction and ease of fish passage was achieved by installing a plywood sheet below the jet (Fig. 3*c*). This sheet acted as a chute, giving the effect of a triangular weir. It was found that the fish

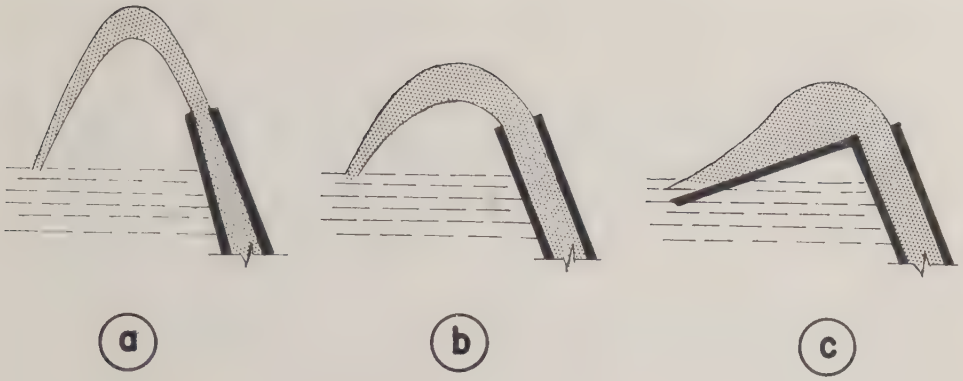


FIGURE 3. *Basic shapes of false waterfall*
(*a*) high velocity discharge
(*b*) low velocity discharge
(*c*) low velocity discharge with plywood chute

preferred to swim the "fall" rather than jump it. The false weir discharge and waterfall shape could be controlled by means of the main 18-inch diameter slide gate, the head control gate (8) and by the hinged baffle (2).

All five species present in the fishway were trapped. The pink and sockeye salmon and steelhead trout were released upstream of the trap and they continued migration after a short recovery time. There was no difficulty in trapping coho, sockeye and chinook salmon and steelhead trout. Pink salmon were reluctant and slow to enter the trap, although a number of them were trapped.

The anaesthetic used was 2 Phenoxy Ethenol, 240 cc of which were used for 425 Imp. gal. Depending on fish size it took from 1 to 5 minutes to completely anaesthetize a fish. Every day the tank was pumped out and a new anaesthetic solution used.

## Conclusion

The operation of the trap showed it to be a practical method of trapping Pacific salmon and steelhead trout. This method of trapping has the following advantages.

1. Because of their anaesthetized state, this method reduces injury to fish while being trapped, handled and transported.
2. The operation of the trap is simple and continuous. This continuity saves time and effort.
3. Construction of the trap and its installation is inexpensive and simple. In most instances the installation would not require permanent structural members.

One limitation to this system is that it requires a water supply with a minimum head of 1.5 to 2 feet. Another limitation is the fact that the installation becomes more complicated in areas where large flow fluctuations are to be expected during the trapping time. Such was the case in the Stamp Falls Fishway. The installation as described in this paper can be greatly simplified under more favourable flow conditions.

# Return of Pink Salmon to Robertson Creek Shows Promise of success

*by*

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A series of pink salmon (*Oncorhynchus gorbuscha*) egg transplants was begun in 1959 to test the feasibility of establishing sizeable runs of pink salmon in the Somass River system on Vancouver Island.

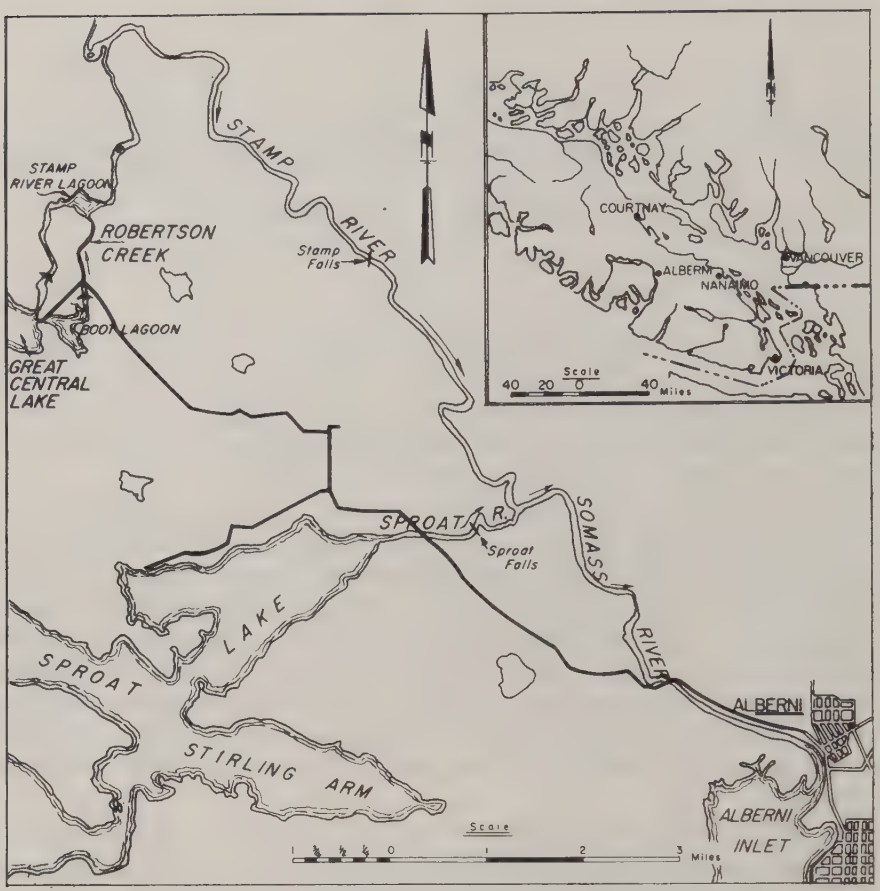
The Somass River is well known for its runs of salmon and steelhead trout (*Salmo gairdnerii*). However, the one species that has never been established in this system in recorded history is the pink salmon. Occasional sightings of pinks have been noted in the lower river in some even-numbered years. Apart from these few fish the river is considered barren of pink salmon. The construction of modern fishways to ease the passage of existing salmon runs over Stamp Falls and Sproat Falls meant that extensive upriver areas were now accessible to the weaker swimming pinks. The completion of an artificial spawning channel at Robertson Creek in the upper Stamp River area made it possible to begin this series of transplants.

The results of these transplants are shown in the accompanying table. It can be seen that two relatively small and three major transplants have been made to date. The results of the small transplants showed that pink salmon would return to this new stream but the numbers were so small that there would be little hope of establishing a continuing run. The returns from the first major transplant were very encouraging when upwards of 4700 fish entered the river and spawned from mid-August to early October (1963).

PINK SALMON EYED EGG TRANSPLANTS AND ADULT RETURNS AT ROBERTSON CREEK SPAWNING CHANNEL

| Year | Donor Stream | Size of Transplant (millions) | % Survival | Adult Return to Channel |
|---|---|---|---|---|
| 1959 | Indian | 1.6 | 95 | 130 |
| 1960 | Tsolum | 0.8 | 89 | 240 |
| 1961 | Indian | 4.8 | 93 | 4133 |
| 1962 | Atnarko | 5.4 | 86 | — |
| 1963 | Indian | 9.7 | (90) | — |

The eggs for this transplant were taken in September from the pink salmon escapement to the Indian River, Burrard Inlet, incubated for a few weeks at the




*Location Map of Somass River System and Robertson Creek.*

Puntledge hatchery near Courtenay, Vancouver Island and transferred prior to hatching to the Robertson Creek Spawning Channel. There, they were buried in the specially prepared gravel beds of the channel. By mid-April, 1962, over 94 per cent of the 4,800,000 eggs placed in the gravel had hatched, absorbed their yolk sacs and commenced a 15-mile downstream migration to the sea.

To provide a reliable estimate of the total adult return, daily counts of spawners entering the Robertson Creek channel were supplemented by repeated spawning ground counts in all portions of the Somass system accessible to pink salmon and in a number of streams flowing into Alberni Inlet which, like the Somass, were known to support small runs of pinks in even-numbered years. In addition, fishery officers in Alberni recorded the catch by sport fishermen in Alberni Inlet and the Indian food fishery in the lower Somass River. In this way the total return has been estimated to exceed 4700. Of this number 4133 returned to spawn in the Robertson Creek channel, 500 spawned in the remainder of the system, a maximum of twenty in a single Alberni Inlet stream and a minimum of 130 were removed by the sport and Indian fisheries.

*Planting Eyed Pink Salmon Eggs in Robertson Creek Spawning Channel*

Several features of the 1963 adult return are most encouraging. The ratio of survival from fry to adult increased tenfold compared with the original 1959-1961 cycle and is triple that of the 1960-1962 cycle. The presence of these spawning fish in other areas of the system could provide a nucleus for future expansion independent of the spawning channel. It is considered probable that the relative

*Adult Pink Salmon Seen Through the Fishery Observation Window at the Entrance to Robertson Creek Spawning Channel.*

success of the 1963 return is a direct reflection of the increased magnitude of the 1961 transplant. To augment the estimated three million eggs deposited by this year's return, an additional 9.7 million eggs were taken from the same donor stream and planted in the Robertson Creek channel. Measurements made throughout the winter indicate that the egg to fry survival will be in the order of 90 per cent. The return of adults in 1965 will be watched with considerable interest since the numbers returning may be sufficiently abundant to establish a pink salmon run in the Somass River system.

# Book Review

*"A Guide to the Study of Freshwater Biology"*, by James G. Needham and Paul R. Needham. Fifth edition, revised and enlarged. Holden-Day, Inc., San Francisco, California.

The fifth revision of this handbook has a number of additions and a few deletions but basically it is similar to early printings. Because several generations of freshwater biologists have "grown up" on *A Guide to the Study of Freshwater Biology*, it has probably become the best known and most used field identification manual on this continent. Dr. Needham explans in the Preface that "the purpose of the book remains the same . . . .: to facilitate the recognition of fresh water organisms both in the field and in the laboratory".

The general arrangement of the text has been maintained in this printing, with a division into two sections. Part I, "Aids to the Recognition of Fresh-water Algae, Invertebrates and Fishes", contains keys, illustrations and references to the various groups of plants and animals dealt with by the authors. Part II, "Methods of Sampling and Analyzing Aquatic Organisms and their Environments", presents information on field equipment, collecting sampling techniques and methods of treating collected material. The final pages of this section deal with methods of studying different types of aquatic environments.

The most noticeable addition to the contents is the inclusion of a section on fresh water fishes. The pages devoted to fish contain definitions and illustrations of body structures, keys with illustrations to fresh water fishes generally and to several of the families containing important sport fish species. Although the section is brief, it is a welcome addition and will be of considerable value to fisheries students and amateur naturalists.

A number of new plates illustrating protozoans, water bugs, caddis-worm houses and aquatic beetles have been added and necessary revisions have been made to all keys. A brief but useful glossary is included in this edition.

This fifth revision of *A Guide to the Study of Freshwater Biology* is an improvement over earlier editions which were, in their day, among the most useful aids in the recognition of fresh water organisms.—E. W. BURRIDGE.